ALLIS-CHALMERS

Electrical Review

June 1945

Electrical Way to Get More Ingots

—WITH AN ALLIS-CHALMERS ARC FURNACE SUBSTATION

LOWERING OPERATION costs and boosting ingot output of arc furnaces is the aim of Allis-Chalmers in designing unit-responsibility substations — like the one illustrated below.

Elements featured in the drawing are quick-acting Regulex electrode control, and a low maintenance furnace switch for disconnect duty, coordinated through the operator's control with furnace transformer and control current transformers.

The sturdy disconnecting switch is expressly designed for repetitive arc furnace duty. Only slight maintenance is needed . . . contacts are long-lived.

Allis-Chalmers also supplies a low-maintenance air blast interrupter for service up to 22,000 volts.

Revolutionary Regulex control, shown below, pays dividends to operators by making possible extra "heats" per day . . . because it's faster-acting.

The Regulex set has no contactors to maintain. Its great amplifying characteristics and instant response to arc current and voltage eliminate power waste — and *all* with the ruggedness and reliability of standard rotating electrical machinery!

As added features, Regulex control can be equipped with flywheels which automatically raise electrodes when power fails, and an auxiliary generator, for making the control independent of a d-c shop source when desired.

Remember, Allis-Chalmers makes a complete line of furnace electrical equipment. There's undivided responsibility — no "buck-passing."

For complete information, call our district office. Or write direct to ALLIS-CHALMERS, MILWAUKEE 1, WIS.

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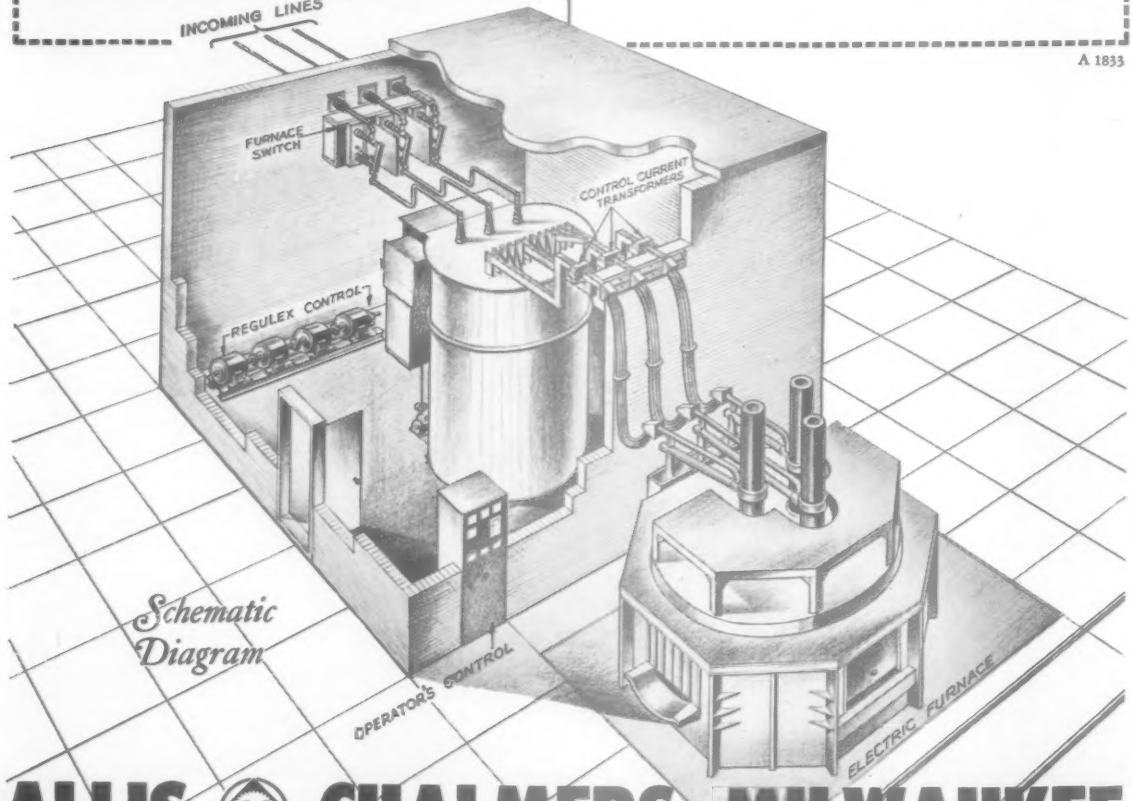

Schematic Diagram

ALLIS AC CHALMERS · MILWAUKEE

HALF A CENTURY of craftsmanship is represented by this veteran motor-builder shown on the front cover, and the two products of his skill. Affectionately he examines the one-half horsepower motor at the left which, as an armature winder's helper, he helped construct in 1894 for an Allis-Chalmers predecessor company. Over 50 years later he applied his skill as a slotter to help produce the modern 1 horsepower motor at right in the photo.

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ALLIS-CHALMERS Electrical REVIEW

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PRE-TEST CHECKUPS always include inspection of air gap uniformity, being done here with a feeler gauge, to determine accuracy of centering of the rotor in the air gap. Generally, a run-in period precedes testing. (FIG. 1).

MOTOR VIBRATION is another factor determined in careful test procedures to ascertain whether or not the amount of vibration is within commercial standards. Preliminary testing also checks for proper lubrication. (FIG. 2).

TESTING YOUR "by"

HENRY T. MURDOCK

Motor* Section, Allis-Chalmers Manufacturing Company

SAFE TEST short-cuts trim hours from time required for complete checking of mass-produced motors with every kind of trial run in the book . . . yet every machine can be guaranteed just like its full-tested proxy.

SO EXTENSIVE and thorough-going are the tests which years of engineering research have devised for predetermining satisfactory motor performance, that putting each unit of a large motor manufacturing plant's daily output through the whole gamut of them would total several thousand man-hours of added effort. In a much more economical approach, carefully devised spot-testing procedures enable motor builders to offer complete guarantees after devoting a fraction of that time to the highly important performance check-ups.

How far can this "spot-testing" go and still fully satisfy the motor operators that their five-out-of-six or 49-out-of-50 or even 99-out-of-100 motors which haven't been given the "works" are just as sure to be satisfactory performers as the chosen few? Obviously, that's the whole problem of successful spot-testing and by now it is guided by well-defined requirements.

Basically, of course, a machine to be adequately checked in a spot-testing system must be one of a number of electrically duplicate motors, so that full tests on one machine can be assumed to be representative of the performance of all. Then, every machine must undergo the spot checks on individual test curves that are indicative of its performance through the complete tests. Also, of course, certain tests cannot be practically applied by spot-checking methods, but must be made on each individual motor. These checks are illustrated and described in Figures 1 to 4.

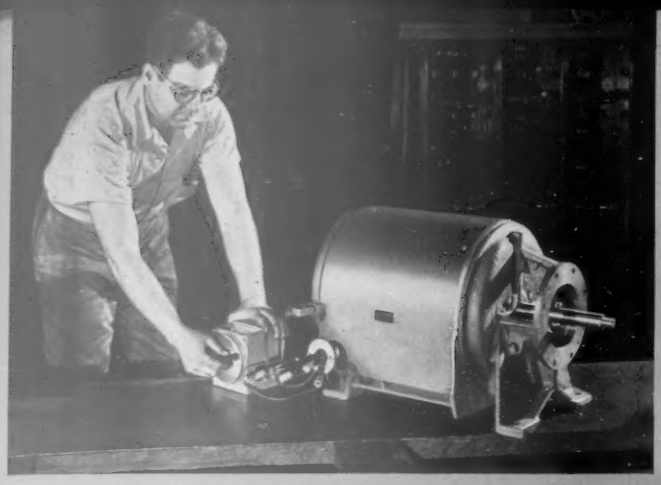
Insofar as operating tests are concerned, the common squirrel-cage induction motors fit into the spot-testing scheme perfectly. Generally mass-produced, they are likewise mass-tested. Careful application of the variety of tests outlined in the accompanying chart will minimize the possibility of misapplication and offer dependable assurance that the machine will perform as guaranteed and avoid the costly loss of man-hours that go with motor failures.

* Allis-Chalmers Norwood Works, Norwood, Ohio.

Application of test results

Complete tests are run on a master unit of a given design machine. These tests, which are outlined on page 6, give sufficient detailed data on a design to allow any duplicate machines to be spot-tested.

After the tests indicated on the charts have been completed on a representative specimen, it is possible to plot curves by which the operating characteristics of the machine at all loads can be determined. This is of great importance when the motor is to be used to drive a machine such as a punch press, crane, lathe, boring mill, etc., where the motor is likely to operate



INSULATION RESISTANCE is checked by megger prior to a high voltage test. One of numerous supplementary tests to guarantee satisfactory motor performance, it precedes check for dielectric strength. (FIG. 3).

DIELECTRIC STRENGTH of this motor is checked with a high voltage transformer. In this "puncture" test, voltage equal to twice rated voltage plus 1000 volts is applied between motor windings and machine frame. (FIG. 4).

R MOTORS

Proxy"

most of the time below its rated horsepower. These light load periods are of particular importance to the operator who is penalized by his power company for low power factor, so that what the curves reveal about them should be particularly helpful.

Three sets of curves and the handy "circle diagram" are derived from the various motor tests. Figure 6 shows the saturation curve (1) and idle loss curve (2) as well as locked rotor current vs. line voltage on locked rotor (Curve 3) and power component current vs. locked rotor current (Curve 4).

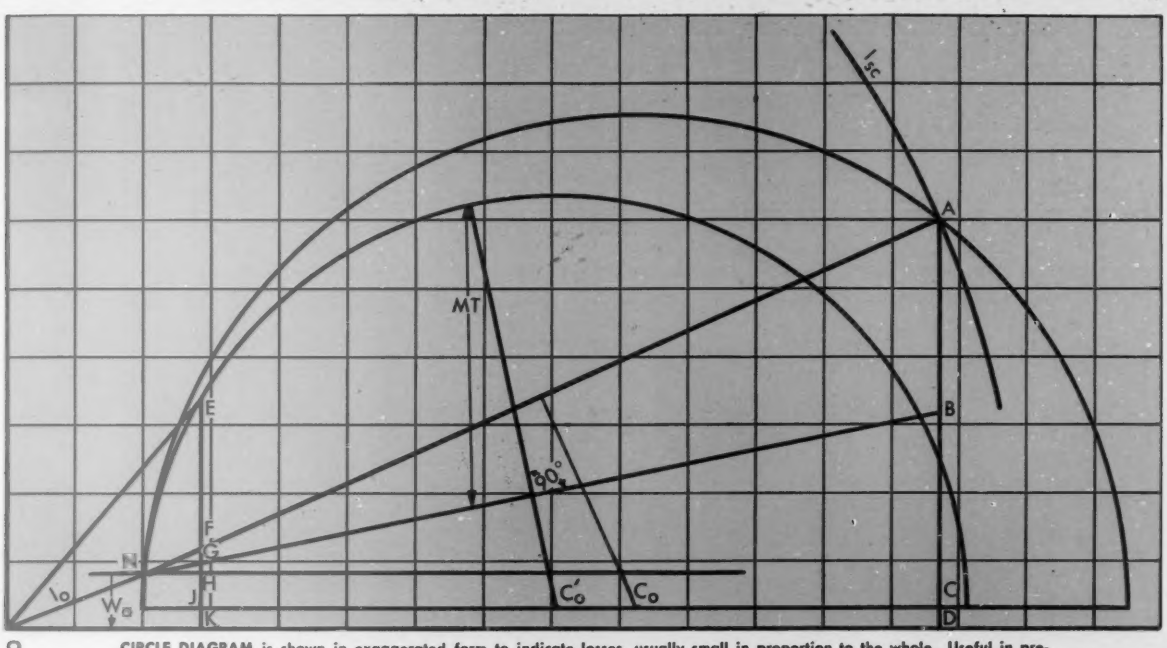
From the no-load saturation curve taken in the test room (Curve 1, Figure 6), stator current is plotted against voltage applied to the stator. The intersection of this curve and the normal voltage line gives the no-load current (shown in Figure 6 as I_o). Also from the same test, the factor "idle watts" is plotted against the voltage applied to the stator (Curve 2, Figure 6). Following approximately the same general shape the curve is extended until it intersects the zero voltage line. At this intersection the windage and friction loss can be read. The intersection of the curve with the normal voltage line (W_o) gives the watts required to drive the motor at no load.

Curves 3 and 4 in Figure 6 are obtained from the locked rotor test. One (Curve 3) is locked rotor current plotted against line volts. It will be noted that at low values of current the curve lies on approximately a straight line, while at higher values of current the curve tends to fall away from the straight line, as shown by the dotted section of the locked rotor curves. This deviation is caused by saturation in the teeth because of the large stator and rotor currents.

COMPLETE TESTS TO DETERMINE CURVES FOR SPOT-TESTING INDUCTION MOTORS

TEST	OBJECT	PROCEDURE	SPECIAL PROVISION	READINGS REQUIRED	RECORD ON TEST SHEET
NO LOAD SATURATION	To determine watts and current required to drive motor at no load.	Connect motor to source of variable voltage and constant frequency consistent with nameplate rating and run at no load through a range of test voltages.	Particularly check bearings and end play prior to testing. If motor has dual voltage rating, run only one connection.	Starting at 125 percent of normal voltage, test at five voltages about 25 percent decreasing voltage steps (one should be near or at normal voltage).	1) Line-to-line voltages 2) Current in at least two lines 3) Power (in watts or kilowatts) taken from line.
LOCKED ROTOR	To determine starting current of motor.	Apply power to stator while rotor is held stationary.	To prevent motor from tipping when power is applied, bolt motor down before clamping bar to shaft to hold rotor. Next, check rotation of motor and clamp bar on rotor shaft so it will not permit rotor to swing around or slip when power is turned on. *Note: If motor overheats, cool to safe value, then resume at same current.*	Starting with current about 75 percent of normal full load value, test at normal full load current and at 150, 200, and 250 percent of normal rated current.	Same readings as above.
STATIC TORQUE	To determine true starting torque of motor.	Same setup as above, plus spring balance or scales (to measure force exerted by rotor)	If bar does not press horizontally on scale platform correct for effect of bar's slant.	One static torque reading at or near normal voltage.	Same as above plus "pounds" (from scales) and length of arm from center of shaft to point of contact on scales.
STRAY LOAD LOSS	With input and output power and other losses known, to determine stray losses.	Test with dynamometer (or accurately calibrated d-c generator of about the same rating); or when two duplicate machines are available, use "pump back" method. Here, two motors are coupled together ("motor" at normal voltages and frequency; "generator" at normal voltage but lower frequency to give desired load).	In "pump back" test, do not change location of meters when direction of power flow is reversed.	At various loads in "Pump back" method, repeat each test with direction of power flow reversed (generator frequency is unchanged and motor frequency raised to give desired load).	Measure input and output, from difference subtract core loss, rotor I^2R, Stator I^2R, windage, and friction to obtain stray losses.
SLIP	To measure slip at various loads percent slip.	Provide for load (preferably with d-c generator) of sufficient capacity to absorb at least 150 percent of nameplate horsepower.	Record readings above normal full load value as quickly as possible to prevent overheating. *Note:* Special care is required to get accurate slip or speed measurements (use slip meter, speed counter, or carefully calibrated tachometer).	Starting at 25 percent of full load current, and increase in 25 percent steps to 150 percent of full load current.	Input voltage, current watts and actual speed (or slip, depending on method used).
FULL LOAD HEAT RUN	To measure operating temperature at full load.	Run motor at nameplate values.	If temperature - measuring - devices are not already installed, place thermometers in required position inside and outside of machine.	Run at constant load until temperatures are constant (length of time depends on size and speed of machine).	Temperatures of coils stator iron, bearings and of air entering and leaving motor as well as ambient temperature at four points surrounding motor.

BEFORE TESTING: Inspect motor for proper assembly, uniform air gap and correct lubrication, as well as shorts or grounds. If motor has not been in service or has just been repaired, run it idle on normal voltage for 15 to 30 minutes to "run in" the bearings (particularly on sleeve bearing machines), keeping careful check on bearing temperatures during run.



CIRCLE DIAGRAM is shown in exaggerated form to indicate losses, usually small in proportion to the whole. Useful in predicting ultimate or maximum torque, circle diagram is a reliable index to motor's probable operating characteristics. (FIG. 5).

The "falling away" characteristic shows the true starting current of the motor. Since the locked rotor current is to be used in plotting the circle diagram (Figure 5), which is to show the comparatively unsaturated running condition of the motor, the straight portion of Curve 3, Figure 6, is extended as a straight line from zero to the normal voltage line. This extension determines the unsaturated value of starting current, and at the point of intersection with the normal voltage line a perpendicular to the base line is erected, as shown in Figure 6.

Curve 4 in Figure 6 is a plot of the power component amperes (I_w) vs. the locked rotor current. The power component current for each test point of the locked rotor curve is calculated as follows:

$$\text{Power component amperes} = \frac{\text{watts}}{1.73 \times \text{volts}}$$

This curve (locked rotor amperes vs. power component amperes) will tend to rise at high values of current. For the same reasons stated in connection with the derivation of the locked rotor amperes curve in Figure 6, extend the curve as a straight line until it intersects the perpendicular erected through the unsaturated locked rotor point. The intersection of I_W and the perpendicular gives the power component amperes for the unsaturated locked rotor point.

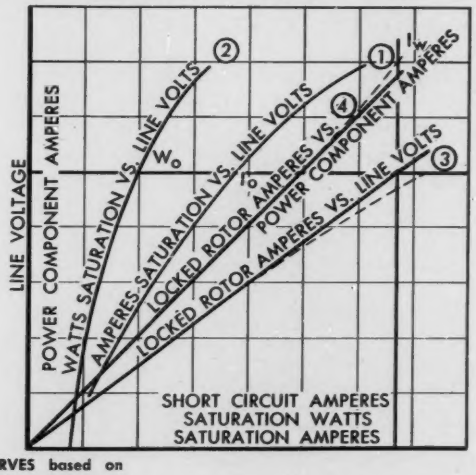
Plotting the circle diagram

After the curves in Figure 6 have been plotted, the circle diagram (Figure 5) can be constructed. It is useful in predicting the breakdown torque of the motor. The circle diagram, as shown in Figure 5, is not in true proportion to that obtained by plotting an actual test, but is constructed in an exaggerated manner to show some of the losses which are usually small in proportion to the whole.

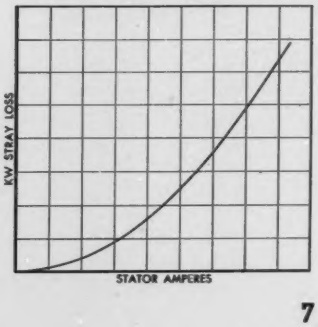
To produce this circle diagram, any convenient scale on rectangular coordinate paper is selected so that the unsaturated locked rotor current taken from Figure 6 will be at least 6 to 8 inches long. Using the short circuit current as a radius, an arc ($I_{sc}A$) is drawn from point 0. To locate point A on this arc, the value of power component amperes (I_w), found from Figure 6, is laid off to the same scale, as shown by AD in Figure 5. This locates one point on the circle. The idle current (I_o) is located in the same manner to become ON, having as its power component:

$$\frac{W_o}{1.73 \times \text{volts}}$$

where W_o = total idle watts at normal voltage



FOUR CURVES based on the no-load saturation and locked rotor motor tests determine windage and friction losses, true starting current and the power component amperes of starting. After these curves are plotted, circle diagram can be constructed. (FIG. 6).



STRAY LOSS TEST provides data for this curve, a plot of stray loss against current. Input, output and other losses must be known to find stray loss. (FIG. 7).

The locus for the center of the circle (C_o) is on the core loss line JC. This line is parallel to the base line, and its distance from the base line is equal to the core loss in power component amperes. The core loss is found as follows:

$$\text{Core loss (in watts)} = W_o - \left[(W + F) + I^2R\right]$$

where W_o = total idle watts at normal voltage
where I^2R = line current squared times terminal-to-terminal resistance at 75C times 1.5.

Upon drawing the line NFA and constructing a perpendicular bisector on this line, the intersection of this bisector and the core loss line (JC) locates the center of the circle (C_o). The circle is then drawn through the points N and A. The line CB represents the stator I^2R loss with locked rotor. To locate this point the stator I^2R loss is calculated and plotted as power component amperes as previously discussed.

It is frequently found that the load points from the load curve do not fall exactly on the circle. If this happens, a second, more accurate, circle can be drawn through the load points with its center, C'_o on the core loss line. Since both circles are used in the same way, everything related here about the second circle is applicable to the circle determined from the no-load points.

It should be kept in mind that, while an induction motor does not follow the circle diagram exactly, its operation throughout the normal load range is close enough to allow prediction of the machine's operating characteristics.[1]

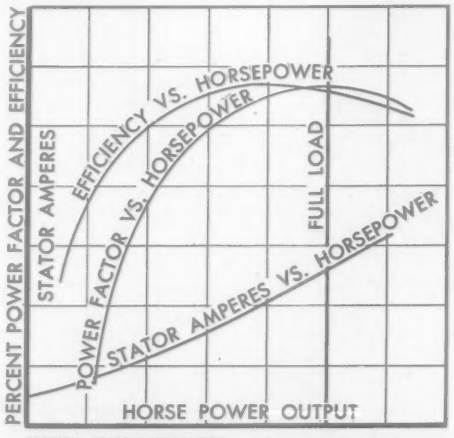
The curve in Figure 7 is a result of the stray loss test, as described in the tabulation, from which the calculated stray loss is plotted against the current at each test point. It shows the approximate variation of stray losses with stator current.

Characteristics in hp output

The three curves in Figure 8 show efficiency, power factor, and stator current, all plotted against horsepower output. They should be calculated from test data, but can be reasonably approximated from the circle diagrams. Perhaps the most useful of any of the curves, they permit machine characteristics to be read directly in terms of horsepower output.

After the tests previously described have been taken, the curves in Figure 8 can be calculated, making use of standard formulas.

Once test data is compiled and all curves have been plotted for a particular type of motor, effective spot-testing of other machines of duplicate design is possible. Checking of a single point on the no-load running current curve and locked rotor current curve, for example, is done with all induction motors, utilizing results of the no-load saturation and locked rotor tests performed "by proxy." Where complete tests of one motor might take two full days, it can be spot-tested in perhaps a half-hour. In this way and this way only is motor testing able to keep pace efficiently with motor mass-production.



MOTOR CHARACTERISTICS can be read directly in terms of horsepower output, against which efficiency, power factor and stator current are plotted above. (FIG. 8).

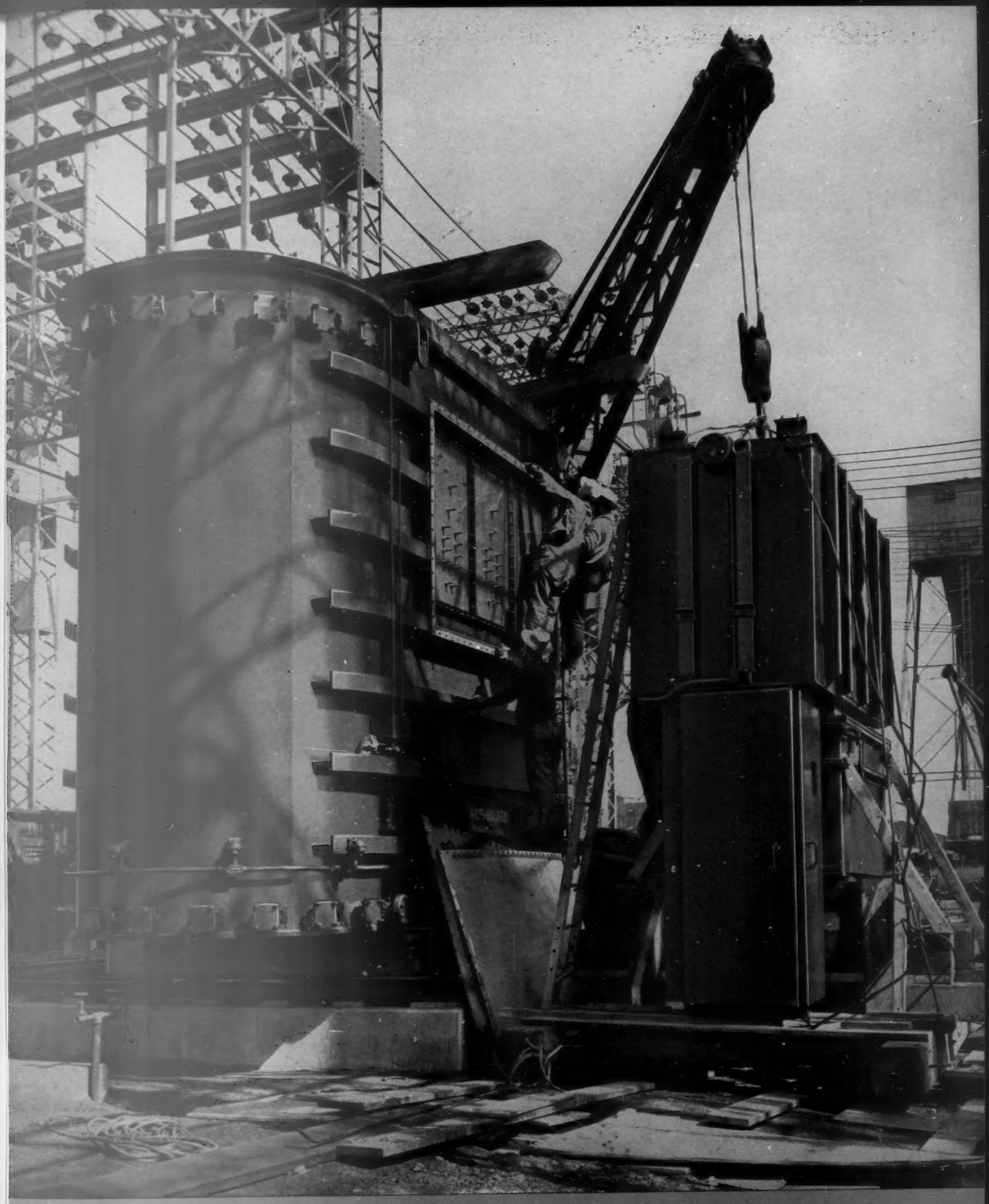
[1] From a circle diagram the following can be determined:

OE	load current (in amperes)
ON	no-load current (in amperes)
EF	output (in power component amperes)
FG	rotor loss (in power component amperes)
GJ	stator I^2R plus windage and friction (in power component amperes)
MT	Maximum torque* (in power component amperes)
JK	core loss (in power component amperes)
$\frac{FG}{EG}$	slip (expressed as a decimal)
$\frac{EK}{OE}$	power factor (expressed as a decimal)
$\frac{EF}{EK}$	efficiency (expressed as a decimal)

* "Maximum torque" here does not take into account an increase in maximum torque caused by saturation.

NO-LOAD SATURATION test determines watts and current required to drive motor at no load, indicates windage, friction losses, above. (FIG. 9).

STATIC TORQUE is determined with same equipment as locked rotor test, with spring balance added to measure force exerted by rotor. (FIG. 10).



THREE MAJOR HIGH-VOLTAGE BUSES in a station of an Indiana public utility will be tied together by this giant 367,000 pound, three-phase transformer, recently installed. Rated 30,000 kva at 138 kv wye; 25,000 kva at 69 kv and 25,000 kva at 34.5 kv delta, the new transformer is equipped with tap-changing-under-load mechanism which can be connected to either the 138 or 69 kv winding.

Modernize Your

It can be a $64,000 Question!

F. T. GIFFORD and S. R. STUBBS
Circuit Breaker Section*
Allis-Chalmers Manufacturing Company

SUCCESS stories of circuit breaker modernization prove that most of the advantages of up-to-date breaker design can often be obtained by rebuilding units that may be 20 or 25 years old.

WHEN SYSTEM growth, new interconnections, or the addition of generating or transformer capacity imposes a duty upon an oil circuit breaker which for one reason or another it is incapable of meeting adequately, two courses of action may be taken:

Either replace the breaker with a modern breaker of adequate rating, or modernize the existing breaker. A modernized breaker will often offer all of the essentials which a modern breaker of equivalent rating will provide, and in fact, modernization of existing breakers is often justified economically as the logical means for obtaining the advantages of modern circuit breaker performance.

What modernization achieves

Fifteen to 20 years ago an oil circuit breaker was considered to be acceptable provided it interrupted its maximum rated short-circuit current without extreme distress. Spilling of oil and emission of gases from the tank was considered to be inevitable when a breaker operated at or near its maximum interrupting rating. In most cases the interrupting contacts were "un-enclosed", the breaker oil tanks being the only enclosure.

In such breakers, the main body of oil was exposed to the arcs which were drawn between the contacts during interruption. Because the gas bubble produced by the heat of each arc was not constricted, it was free to expand within the oil surrounding the contacts, thus delaying the rapid increase of pressure and turbulence between the contacts necessary to prevent re-ignition of the arc following an early current zero, and thereby achieving interruption of the circuit.

Consequently, the arcing period was long; erosion of the contacts, oil deterioration and the stresses upon the breaker structure (due to the prolonged release of arc energy) were severe; high internal pressures were ultimately imposed directly upon the tank wall; considerable throwing of oil was inevitable and frequent servicing of the breaker was necessary.

The speed of opening of such breakers, from energization of the opening coil to interruption of the circuit was generally of the order of from 0.25 to 0.83 seconds. Many of these breakers were operated by non-trip free operating mechanisms which permitted the closing, and holding of a breaker closed, as long as closing effort was applied, during a short-circuit.

At that time also the standard duty cycle, upon which the interrupting ratings of the breakers were based, consisted of a closure followed by an immediate reopening of the breaker (without purposely delayed action) followed after the expiration of a 2-minute interval, by another closure and immediate reopening. This was referred to as the OCO (open-closed-open) 2-minute-OCO duty cycle.

In contrast, present-day standard breakers of 50,000 kva interrupting capacity and above are required to be of oil-tight construction and, up to and including the 69 kv class, are required to interrupt faults in the range from 25 percent to 100 percent of their interrupting ratings, in not more than 8 cycles on a 60 cycle circuit (0.133 seconds) after the instant of energization of their trip coils. Breakers rated 115 kv and above are required to interrupt faults in the same percent rating range, in not more than 5 cycles on a 60 cycle circuit (0.0833 seconds).

In addition, most modern breakers are electrically and mechanically trip-free in order to prevent the possibility of holding a breaker closed during a short-circuit. Their insulation levels are also frequently as much as 30 percent or more higher than those of older breakers of similar voltage rating, particularly in the case of outdoor breakers.

Modernization then, as the term implies, involves an increase in the interrupting capacity and/or such improvements in the interrupting performance, and the electrical and mechanical characteristics of an existing breaker as will render it capable of approaching or equaling the performance of an equivalent modern breaker.

To modernize or not to modernize

The final decision whether to modernize or replace an existing breaker can only be reached after a careful appraisal of all of the many technical and economic factors involved. On the one hand is the indisputable advantage of obtaining an accurately coordinated,

* Allis-Chalmers Boston Works, Boston, Massachusetts

r Breakers?

largely standard, completely new, thoroughly modern product which will be ready for installation when received. On the other hand, modernization of the existing breaker is sometimes justifiable, although it is obvious that a modernized breaker is not necessarily the true counterpart of a modern breaker of equivalent rating.

While its performance may be greatly improved by modernization to the point where it can provide all of the essentials of the modern breaker under the particular circumstances, it necessarily constitutes a compromise between the old and the new which, except in rare cases, prevents the full realization of that high degree of coordination of functions which modern oil circuit breakers provide.

In addition, the necessity of maintaining service often precludes the return of the obsolete breaker to the factory for modernization. Consequently, the application of the new parts involved in the modernization process has to be carried out in the field, often entailing considerable additional expense.

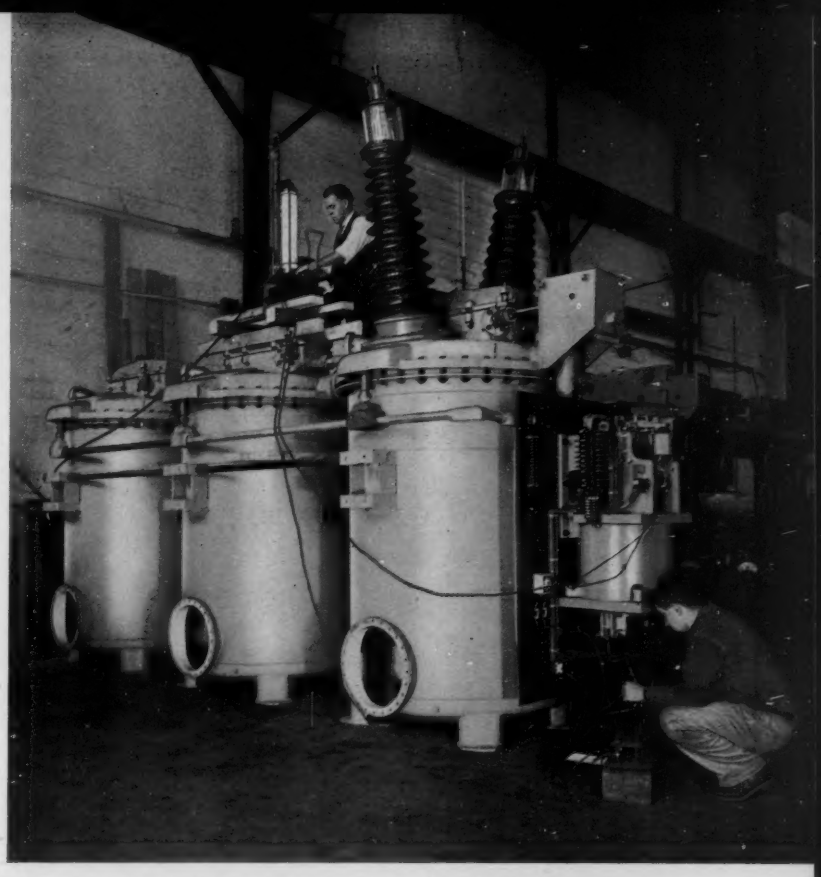
The decision also does not always depend upon the circuit breaker alone, particularly in the case of indoor circuit breakers, which are usually installed in concrete or steel structures. In such cases, whatever is done in the way of improving the performance of the breaker must be accomplished within the space occupied by the existing breaker and, preferably, with the same arrangement of leads. Also, many old, common top frame, indoor oil circuit breakers have their poles arranged one behind the other, while most modern breakers have their poles arranged side by side when viewed from the front of the breaker. Consequently, the installation of a new breaker in an existing cell usually necessitates a rearrangement of the terminal leads and often causes other complications in mounting. Modernization involves only the circuit breaker structure, so that the expense of rebuilding existing cells and/or rearranging leads is avoided.

Each modernization project necessarily presents its own peculiar engineering problems. Special new parts often have to be designed and made. Hence, unless a large quantity of obsolete breakers of a given type and size are modernized substantially at the same time, thereby reducing the engineering cost per breaker and enabling the realization of production savings, the overall cost of the modernization may approach and perhaps exceed the installed cost of a new breaker.

Nevertheless, there are many cases where modernization is economically justifiable.

How arc-enclosure increases capacity

The interrupting ability of obsolete breakers with "unenclosed" contacts, such as those described above, can usually be considerably improved by the application of suitably designed arc-enclosing devices, together with improvement of the operating characteristics of the breaker, if necessary, to enable the interrupting devices to perform most efficiently. One form of arc-enclosure is the Ruptor arc interrupter shown in Figure 2.



FACTORY MODERNIZATION of this oil circuit breaker (Type BZO-70-110D) completed, the 400 ampere, 110 kv unit is put through operating speed tests before being shipped to a Southern utility system which needed improved interrupting performance for better system stability. Modernization improved its 1,000,000 kva interrupting capacity from the previous OCO-2 minute-OCO duty cycle to a CO-15 second-CO duty cycle. (FIG. 1).

This Ruptor arc interrupting device is an arc-enclosure of special design. It comprises two main physical parts: the upper part or hood, which houses the stationary arcing contact assembly; and the lower portion or shell group, which includes the oil reservoir or pressure generating chamber and the throat or arc-extinguishing chamber, which combines a central passage and a surrounding helical configuration. A complete Ruptor device is mounted directly on each oil circuit breaker stud.

During closing, the bayonet-type, movable arcing contact enters the bottom of the enclosure through the throat, passes through the oil reservoir and slides into the tulip type stationary arcing contacts with a wedge action.

Upon tripping of the oil circuit breaker mechanism, all of the movable bayonet contacts move downward simultaneously, breaking contact with the stationary contacts after a short travel during which their speed has been very rapidly accelerated. The moving contact

then passes through the oil reservoir or pressure generating chamber and continues downward through the restricted passage in the throat and finally into the main body of insulating oil within the circuit breaker tank.

Due to the high degree of limitation and control of arc energy exerted by the Ruptor arc interrupting device, arc duration, oil deterioration and tank pressure are held to a minimum, as is illustrated in Figures 3a, 3b, and 3c, which show curves comparing arc energies, oil deteriorations, and tank pressures respectively, obtained with a breaker equipped with Ruptor contacts and with a plain break breaker having magnetic loop contacts. Consequently, the dielectric and functional integrity of the breaker is preserved and maintenance costs are minimized.

Where to modernize

Modernization is usually most justifiable when these arc-enclosing devices can be applied and the desired increase of interrupting ability achieved without too drastic change in other parts of the breaker. Circuit interruption within 8 cycles, as required under present-day standards, necessitates parting of the interrupting contacts in 4 cycles or less after energization of the opening coil. Where the opening speed of the existing breaker approaches these requirements, or where the application of stronger accelerating springs will enable an existing breaker to achieve the desired speed of opening, modernization is a comparatively simple matter.

In the latter case, increased closing effort may be required to compress the stronger accelerating springs. Where the breaker is electrically operated, therefore, stronger closing solenoid coils sometimes have to be applied. The heavier accelerating springs also increase the load on the latch which holds the breaker closed. This may necessitate the application of a stronger opening solenoid or trip coil.

The space occupied by the arc-enclosing devices and their cooperating movable bayonet contacts is often considerably greater than that occupied by the plain contacts formerly used. Modernized breakers, therefore, usually require deeper oil tanks for the accommodation of the new contact structure. In the larger breakers, the increased tank depth can be provided by welding extension bands to the tops of the existing tanks. In the smaller breakers it is usually more economical and satisfactory to furnish new, deeper tanks.

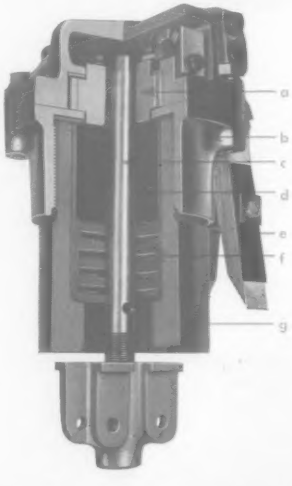
Incidental to the modernization process, where the internal diameter of the existing circuit breaker bushings permit, the normal current-carrying capacity can be increased by the application of new bushing terminal studs of larger cross-section, providing the increase in current will not cause undue heating of the existing top frame due to eddy currents.

Modernization case histories

1—Breakers modernized at half-cost

An eastern utility installed a large number of 400 ampere, 15 kv, 3-pole, manually remote-operated, indoor oil circuit breakers of the type shown in Figure 4a, during the period 1921-1929. When installed, the breakers were rated 65,000 kva interrupting capacity on a 2-minute duty cycle (OCO-2 minute-OCO). By 1936, due to system growth, the short circuit kva which the breaker might have to interrupt had more than doubled. Consequently, the interrupting capacity of the breakers had to be increased or, alternatively, the breakers would have to be replaced by modern breakers of higher interrupting rating.

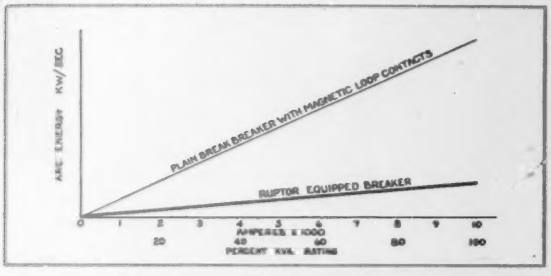
Investigation of the possibility of increasing the interrupting ability of the existing breakers showed that the application of the smallest standard Ruptor contacts, as used in modern 100,000 kva, 15 kv breakers, would involve a considerable increase in tank depth necessitating an expensive change in the mounting of the breakers. This, of course, it was considered preferable to avoid. As the service voltage was 2300, the voltage rating of the breakers was reduced to 5000, and a special Ruptor arc interrupting device was developed for attachment to the existing contact blocks. While application of this device required a 1 inch greater contact separation and a somewhat deeper tank, it would still permit removal of the tank for servicing with the contacts closed, without any change in the breaker mounting. This was possible because disconnects were connected in series with the breakers.



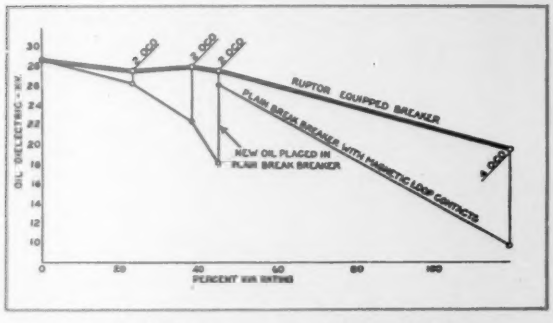
a. Stationary arcing contact.
b. Bronze hood.
c. Movable bayonet type arcing contact.
d. Oil reservoir or pressure generating chamber.
e. Stationary current carrying contacts.
f. Helical throat passage.
g. Bakelain shell.

ARC-ENCLOSING DEVICE, known as the Ruptor arc interrupter, improves interrupting ability of obsolete breakers with "unenclosed" contacts. (FIG. 2).

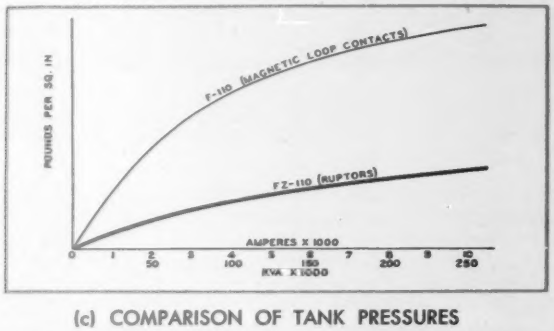
Initially, 20 breakers were modernized with the special Ruptor contacts, as shown in Figure 4b, the complementary equipment including new accelerating springs, as well as the deeper tanks. Shortly after installation of the new parts, one of the breakers was called upon to interrupt a severe short circuit, and, in accordance with station procedure, was closed in against the fault after three minutes. It therefore performed an O-3 minute -CO duty cycle. The current closed and interrupted was between 26,000 and 48,200 RMS amperes, the short-circuit being known to be in the range from 105,000 to 192,000 kva. Investigation showed that the interrupting contacts were still capable of standing four or five more interruptions of



(a) COMPARISON OF ARC ENERGIES



(b) COMPARISON OF OIL DETERIORATIONS



(c) COMPARISON OF TANK PRESSURES

RUPTOR CONTACTS on one breaker hold arc duration, oil deterioration and tank pressure to a minimum, as compared with a plain break breaker. (FIG. 3).

equal magnitude, and that the oil tested 24.15 kv (average breakdown in standard test cup).

Subsequently, close to 200 breakers were modernized in a similar manner, and some of these withstood repeated short-circuits between 120,000 and 150,000 kva. One breaker was estimated to have withstood five interruptions (O and CO shots) at 30,000 to 38,000 RMS amperes, and two closures (on CO shots) the inrush current range of which was 30,000 to 63,000 amperes RMS. In the performance of this duty, somewhat more than half the useful life of the contacts had been expended.

Since the breakers had un-enclosed mechanisms (the lift rods passing through holes in the breaker top frame), some oil was thrown when the breakers interrupted these heavy short circuits, but due to the pressure control exerted by the Ruptor device, the amount of oil thrown was limited to less than a cupful in each case. The addition of lift rod glands, operating shaft packings, and oil and gas separators, to such modernized breakers would render them practically oil-tight.

Since the cost of the modernization parts was less than half of the cost of modern breakers of 100,000 kva interrupting rating, modernization of the existing breakers paid generously in this case.

2—*Interrupting capacity increased 125%*

A midwestern utility wished to increase the interrupting capacity of a small quantity of 400 ampere, 15 kv, 3-pole breakers of the type shown in Figure 5a. The interrupting capacity at the time of installation (1921-1927) was 110,000 kva on a 2-minute duty cycle. Investigation showed that by applying Ruptor contacts, as used in modern breakers of 150,000 kva rating at 15 kv, and by suitably accelerating the opening speed, the existing breakers could be assigned a new interrupting rating of 150,000 kva at 15 kv on a CO-15 second-CO duty cycle. One of these modernized breakers is shown in Figure 5b.

At the time this modernized breaker (shown in Figure 5a) was designed, the depth of oil above the contacts was considered to be an important factor contributing to the interrupting efficiency. The oil ends of the porcelain bushings were made considerably longer than was necessary, therefore, for insulation reasons alone. Since the enclosed Ruptor contacts did not require such deep immersion, it was possible to cut approximately 3 inches off the lower end of the bushings. It was then possible to accommodate the new contacts, with an unchanged opening stroke, within new tanks, but 3½ inches deeper than those formerly used. In addition, the modernization material included stronger accelerating and impulse springs, new external shock absorbers, and new 600 ampere terminal studs.

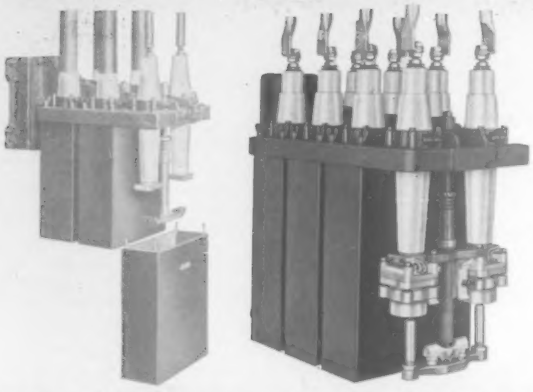
Though the breakers originally had an interrupting rating of 100,000 kva on a 2-minute duty cycle, various derating factors (since adopted by the joint committee of the AIEE, NEMA, and AEIC) would reduce the rating to 66,000 kva on a "present-day" 15-second duty cycle basis. Hence, the interrupting capacity of the breakers was increased over 125 percent with an incidental increase in current-carrying capacity of 50 percent.

Again in this case, breakers were modernized to provide all of the essentials which modern breakers of equivalent rating would have provided at a parts cost considerably less than one-half the cost of the modern breaker.

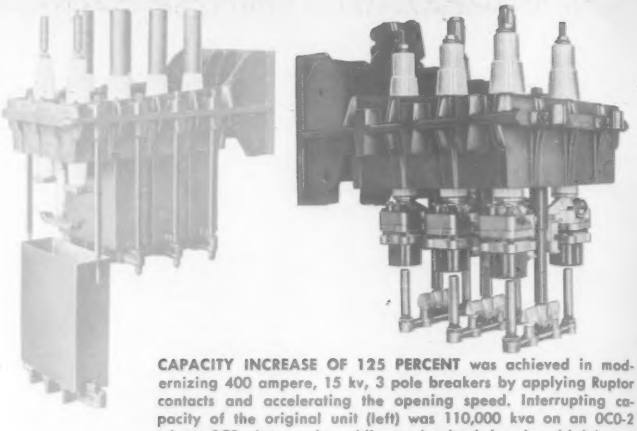
3—*Field tests confirm increased ratings*

Due to system conditions, it became necessary to improve the interrupting ability of a number of 600 ampere, 37 kv, 750,000 kva interrupting capacity (on a 2-minute duty cycle) 3-pole, 4-break, outdoor oil circuit breakers installed during the period from 1925-1929 on the 26 kv system of a large eastern utility.

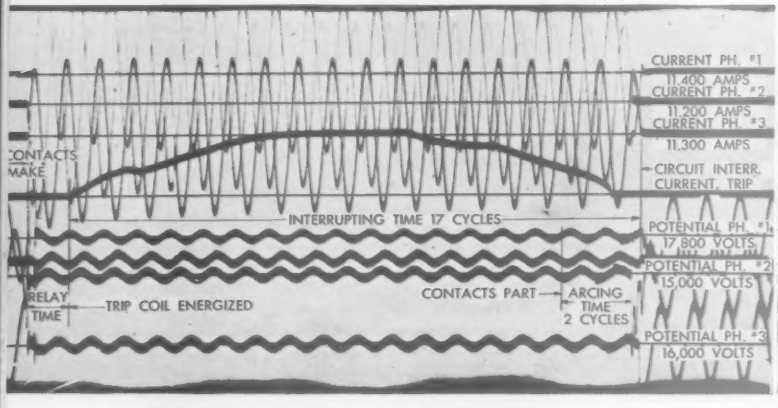
One breaker was returned to the factory to be equipped with Ruptor contacts and only new lift rod guides and new liners for the existing tanks in addition. The 9½-inch opening stroke previously used in conjunction with the 4-break contact arrangement was not changed even though it was 1½ inches shorter than the stroke for a 34.5 (2-break) standard Ruptor breaker. The existing non-trip free solenoid operator was left unchanged. The breaker was then proof-tested by the utility to confirm its interrupting rating.



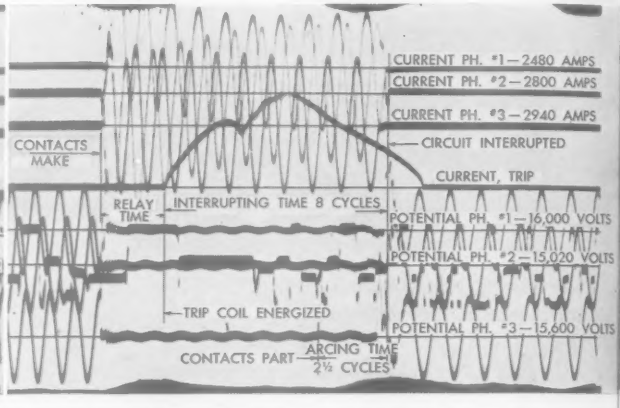
DOUBLED SHORT-CIRCUIT KVA which this 10-year-old indoor oil circuit breaker (left) was compelled to interrupt, as a result of system growth, necessitated replacement or modernization. Modernized Type DZ-22, 600 ampere, 5000 volt breaker is shown at the right above. (FIG. 4).



CAPACITY INCREASE OF 125 PERCENT was achieved in modernizing 400 ampere, 15 kv, 3 pole breakers by applying Ruptor contacts and accelerating the opening speed. Interrupting capacity of the original unit (left) was 110,000 kva on an OCO-2 minute-OCO duty cycle, while modernized breaker (right) was assigned a new interrupting rating of 150,000 kva on a CO-15 second-CO duty cycle. (FIG. 5).



OSCILLOGRAPHIC RECORD (left) of interruption of approximately 11,200 RMS amperes at 26,000 volts by a modernized breaker (Type FZO-40-37C) satisfied the utility that it could meet its newly assigned rating. (FIG. 6a).



MORE COMPLETE MODERNIZATION enabled a newly designated Type FZO-40-34D breaker to interrupt approximately 2800 RMS amperes at 16,000 volts, within 8 cycles from energization of trip coil. (FIG. 6b).

During the test, the breaker performed two interruptions at 3000 RMS amperes (on an OCO-2 minute-OCO basis), followed by two interruptions at 11,000 amperes on the same duty cycle. The test voltage was approximately 16,000 volts, phase to ground. Subsequent investigation shows that the contacts were still in good condition and that the dielectric level of the oil was unimpaired.

In an oscillogram taken during one of the 11,000 ampere interruptions (Figure 6a), the interrupting time, from energization of trip coil to interruption of the circuit is indicated to be approximately seventeen cycles. The test consisted of the breaker closing a short-circuited line and immediately reopening (setup shown in Figure 7). Since the closing solenoid operator had a non-trip free mechanism, the direction of motion of the whole moving system, including the solenoid armature and its connected linkages, had to be reversed before the breaker could start its opening stroke.

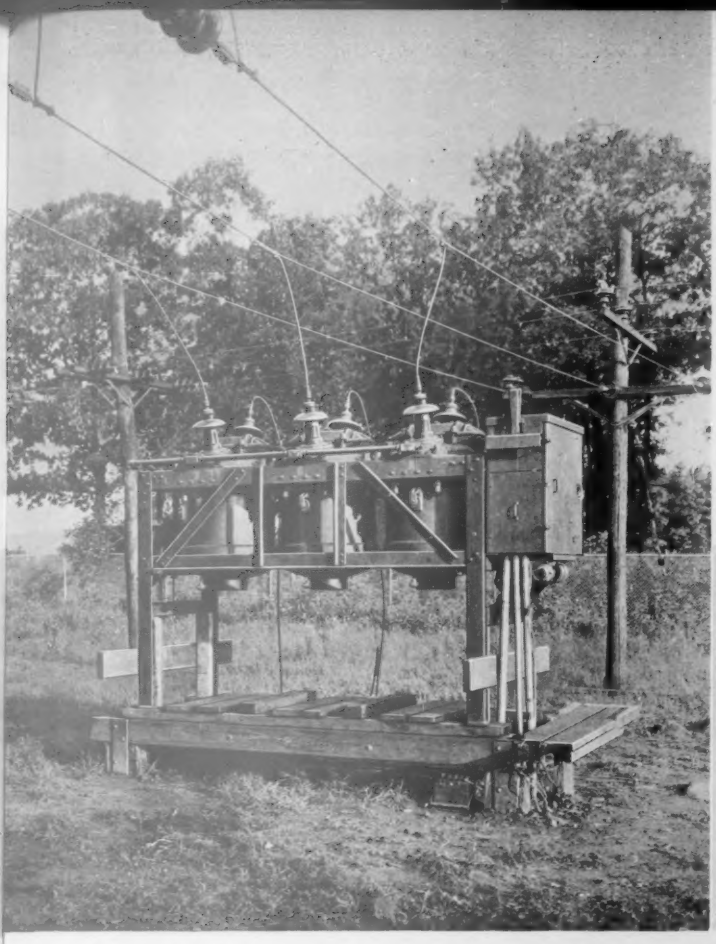
The high inertia of this moving system was not conducive to a speedy accomplishment of this close-open cycle, and in addition, the residual magnetism of the solenoid armature further retarded the reopening of the breaker. Hence, interruption of the circuit was delayed and the interrupting time was relatively long.

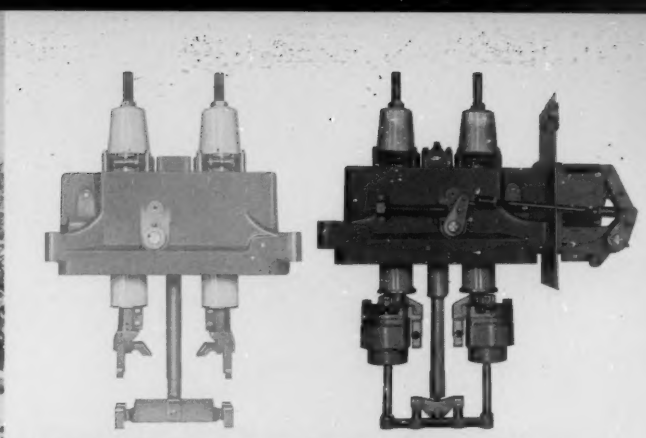
Throughout the series of tests the breaker operated without distress and no appreciable amount of oil was thrown, even though the tanks were not gasketed. Because the utility was satisfied that the performance of the breaker when interrupting 3,000 and 11,000 amperes was sufficient evidence of the ability of the breaker to meet its rating, a further scheduled test at 16,000 RMS amperes was omitted.

On the basis of the satisfactory performance of the breaker during these proof tests, the interrupting ability of over 30 breakers of the same type was subsequently improved in a similar manner, the Ruptor contacts and other parts being installed in the field. Later a number of these breakers were more completely revamped with tank gaskets, lift rod guides, accelerating springs, and new bushings, in addition to the new Ruptor contacts. These breakers were then assigned a rating of 1,000,000 kva at 34.5 kv on a 15-second duty cycle. Complete modernization of one breaker was achieved by applying modern, mechanically and electrically trip-free solenoid operator in addition to Ruptor contacts and associated parts. This enabled the breaker to interrupt the circuit within the present-day NEMA standard interrupting time of 8 cycles. Figure 6b is an oscillographic record of the interruption within 8 cycles, of approximately 2800 amperes at 26,000 volts by such a completely modernized breaker.

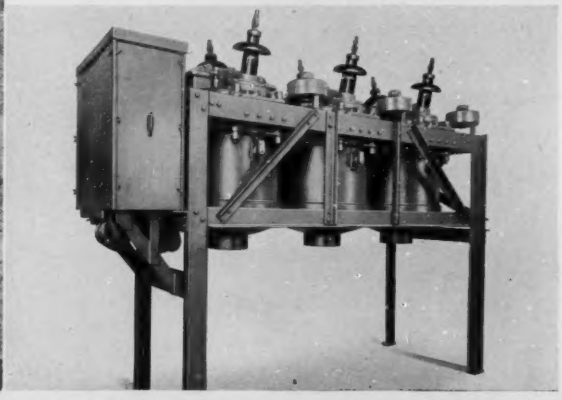
The original 37 kv bushings had flashover values of 110 kv dry, 85 kv wet, and approximately 180 kv impulse. The replacing 34.5 kv bushings had flashover values of 150 kv dry, 110 kv wet, and 250 kv impulse.

Since the interrupting rating of the breakers before modernization would have been 450,000 kva when





OVER 700 BREAKERS like this (left), originally installed between 1922 and 1929, had interrupting capacities increased from 210,000 kva on an OCO-2 minute OCO duty cycle to 300,000 kva on a CO-2 minute CO duty cycle for the midwestern utility's new breaker, at right above. (FIG. 8).



FIELD TESTS are being conducted to establish newly increased interrupting capacity of modernized outdoor oil circuit breaker. Throughout tests, breakers operated without distress, threw no appreciable amount of oil. (FIG. 7).

COMPLETE REBUILDING of breakers in the field, where facilities for handling heavy parts are unavailable, sometimes makes modernization inadvisable. Owner of this unit rebuilt eight units in the field. (FIG. 9).

derated to meet the present-day 15-second duty cycle, the new interrupting rating represented an increase in interrupting capacity, due to modernization, of over 100 percent. At the same time, the application of new bushings raised the dielectric level of the breakers over 30 percent — all this at a cost for the modernizing parts of less than 40 percent of the cost of a modern breaker of the nearest standard rating (1200 ampere, 34.5 kv, 1,000,000 kva).

4—Modernize over 700 breakers successfully

A large midwestern utility desired to improve the interrupting ability of a large number of 600 ampere, 15 kv, indoor, cell-mounted, breakers of the type shown in Figure 8a. The interrupting capacity of these breakers at the time of installation (1922-1929) was 210,000 kva on a 2-minute duty cycle. A trial installation was first made on one 3-pole breaker, the modernizing parts consisting of new lift rods, shock absorbers, accelerating springs, and deeper tanks, in addition to Ruptor contacts. By modifying the original breaker truck mounting carriage, the new tanks were accommodated without increasing the overall breaker height. The existing non-trip free solenoid operators were left unchanged.

Space limitations within the breaker cells did not permit the application of oil and gas separators, and as the breakers had cast iron top frames, it was not possible to assign the new interrupting rating on the basis of the oil-tight (CO-15 second-CO) duty cycle, despite the fact that the application of the new parts enabled the breaker to interrupt within 8 cycles. Hence, the modernized breaker (shown in Figure 8b) was rated 300,000 kva on a 2-minute duty cycle basis.

The success of the trial installation is attested by the fact that over 700 single pole units of the same type for use in various 1, 2, and 3 pole combinations were subsequently modernized in a similar manner. To have obtained the same interrupting rating in a modern breaker would have involved the purchase of new equipment having the next highest standard interrupting rating of 500,000 kva on a 15-second duty cycle basis. Such breakers would have involved more than three times the cost of the modernizing parts.

5—Problem: cost of field changeover

Due to system growth, it became necessary to increase the interrupting capacity of a number of 1200 ampere, 25 kv, 1,000,000 kva (2-minute duty cycle) outdoor oil circuit breakers (of the type shown in Figure 9) installed 12 to 15 years earlier by a midwestern utility. System requirements dictated rendering the breakers capable of interrupting 1,250,000 kva at 12 kv on a 15-second duty cycle within 8 cycles after energization of the opening coil. Investigation showed that this would necessitate an almost complete rebuilding of the breakers.

One breaker was returned to the factory for modernization. The old 4-break magnetic loop contacts, shown in Figure 10a, were replaced by Ruptor contacts,

new lift rods and rod guides, as shown in Figure 10b, necessitating deepening of the tanks by means of extension bands welded to the tank rims, and also new tank liners and tank bolts. In order to enable the breaker to meet the 8-cycle interrupting requirements, it was necessary to replace the old non-trip free solenoid operating mechanism, its enclosing cabinet and the front of the breaker supporting frame to which they were attached with a modern mechanically and electrically trip-free solenoid operator and accessories. This unit, mounted in a weatherproof cabinet on a new frame front end, is shown in Figure 11. New pole unit mechanisms, accelerating springs, and tank gaskets were also added.

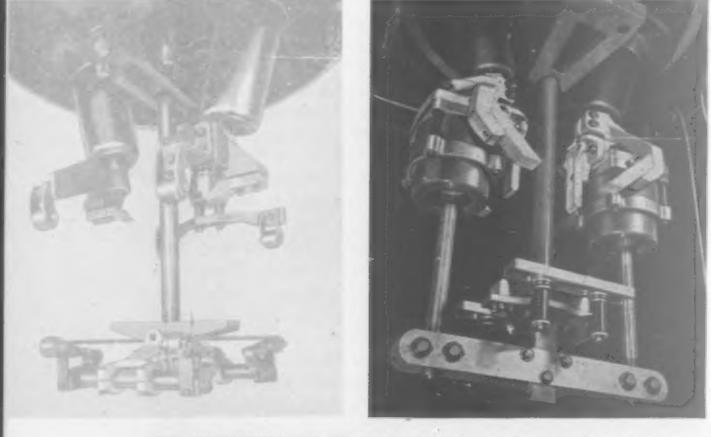
Hence, the breaker top frame and its bushings were the only parts not modified or replaced. Subsequently, eight additional breakers were modernized in the same manner, except that the modernizing parts were applied to the existing breakers in the field. In these cases, however, the new frame front ends were made up in the factory and shipped complete, as shown in Figure 11.

Such a modernization project necessarily involves almost completely disassembling and reassembling the breaker in the field, where lack of adequate facilities for handling heavy parts is liable to prove a handicap. Since such work has usually to be done during periods of light load, such as week-ends, high labor costs are frequently involved. Lack of familiarity with the new parts and their adjustment is also an adverse factor, particularly during the modernization of the first few breakers.

As a consequence of these factors, the cost of the changeover in the field may be high. Since the cost of the modernizing parts may represent a considerable percentage of the cost of a modern replacing breaker of equivalent rating, the technical and economic factors involved in such a complete modernization have to be very carefully considered.

6—System stability requirement met

System conditions on a southern utility necessitated improving the interrupting performance of a small quantity of 110 kv, 400 ampere, outdoor oil circuit breakers installed during the late 1920's. The breakers had an interrupting rating of 1,000,000 kva on a 2-minute duty cycle. Their interrupting time was of the order of 12 to 14 cycles, 8 cycles of which was consumed in overcoming the inertia of the moving parts and in parting the contacts. Consideration of system stability made it necessary for the breakers to be capable of performing a 15-second interrupting duty cycle and of interrupting the circuit within 8 cycles. Investigation showed that the required modernization would involve such a complete disassembly and rebuilding of the breakers that it was not feasible for the work to be done in the field. The breakers were accordingly returned to the factory for modernization.



OLD MAGNETIC LOOP CONTACTS (left) for the breaker shown in Figure 9 were replaced by Ruptor contacts, new lift rods, and rod guides (right), necessitating deepening of the tanks in rebuilding. (FIG. 10).

The original breakers had slow-moving, rotating pole unit mechanisms which provided a 10-inch stroke as required by the original 10 open breaks in series. These had to be replaced by modern high-speed toggle mechanisms to provide the 20-inch travel required by the two-break Ruptor contacts. This entailed burning a large rectangular hole in the steel top frame of each pole, and welding in rectangular mechanism wells for accommodation of the new pole unit mechanisms. Also, oil and gas separator and emergency gas vent seatings had to be welded into each top frame. A new housing for accommodation of operating bell cranks and a position indicator had also to be welded onto the front of each forward pole top.

The increased contact travel necessitated a corresponding increase in tank depth. This was achieved by burning off the tank tops with their bolting flanges, welding tank extension bands to the tanks and then replacing the bolting flanges by welding them to the top of the extension bands. The original operating mechanism was also inadequate and had to be replaced by an electrically and mechanically trip-free solenoid operator of modern design. This entailed welding a steel plate to the front of each forward pole for the support of the new operator, its accessories and its enclosing weatherproof housing. One of the modernized breakers, approaching completion, is shown in Figure 1 undergoing operating speed tests in the factory.

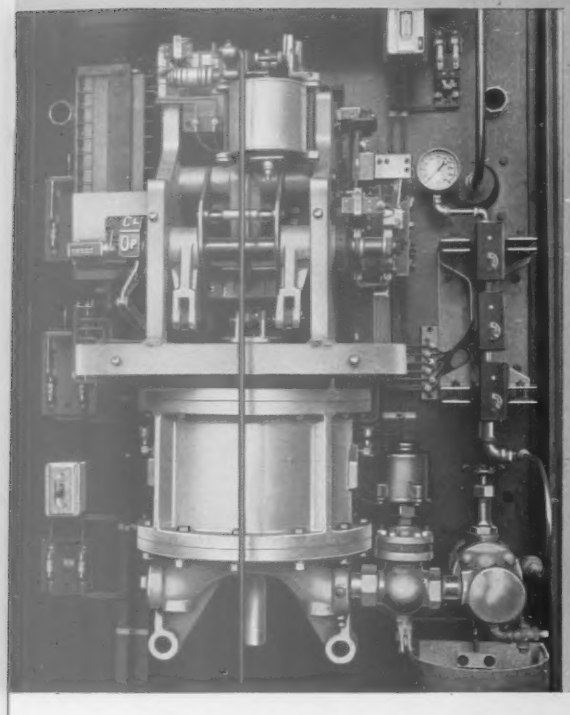
The existing oil-filled bushings also were modernized. This involved completely replacing the internal insulation with new concentric Bakelain tubes. The original bushings had a 330 kv dry flashover value and would not withstand more than 270 kv for one minute. When modernized, they withstood 350 kv for one minute and their dry flashover value was 385 kv.

After modernization, the breakers were assigned an 8-cycle interrupting rating of 1,000,000 kva on a 15-second duty cycle. In this case, the bushing current transformers were the only parts of the breakers not modified or replaced, and the overall cost of such a modernization necessarily approaches (and may even exceed) the cost of a new replacing breaker of equivalent modern rating.

7-Modernization assures service continuity

Considerations of service continuity on an important 110 kv line in the system of a large eastern utility, made it necessary to sufficiently improve the interrupting performance of the outdoor oil circuit breaker controlling the line (of the same type and rating as referred to in Case 6) to permit high-speed reclosing of the line under fault conditions. As in Case 6, it was necessary to return the breaker to the factory for modernization but, because the breaker had cast iron top frames, new cast steel top frames incorporating the necessary pole unit mechanism wells had to be applied.

NEW FRAME FRONT END units for modernized breaker illustrated in Figure 9 were made at the factory and shipped to utility system for field installation. Modern trip-free solenoid operator in weatherproof cabinet is being inspected by the workman shown here. (FIG. 11).



PNEUMATIC OPERATOR, with motor-driven compressor and control equipment, is type applied to large outdoor oil circuit breaker, shown in Figure 1. (FIG. 12).

Reduction of the interrupting time to 8 cycles and the improvement in interrupting performance, due to the application of Ruptor contacts, provided early enough clearance of line faults and maintained satisfactory breaker interrupting ability, permitted the desired speed of reclosing and enabled the breaker to immediately re-interrupt the fault, when necessary, at the same time maintaining the interrupting ability of the breaker sufficiently to permit it to perform the remainder of its scheduled reclosing cycle — which might entail two additional reclosures and interruptions at more prolonged intervals. In order to take full advantage of the improved interrupting ability of the breaker, however, it was necessary to apply a pneumatic operator to the modernized breaker. This enabled the breaker to be reclosed within 23 cycles, measured from energization of the opening coil to contacts touch during closing.

The type of pneumatic operator used, with a motor-driven compressor and control equipment, is shown in Figure 12.

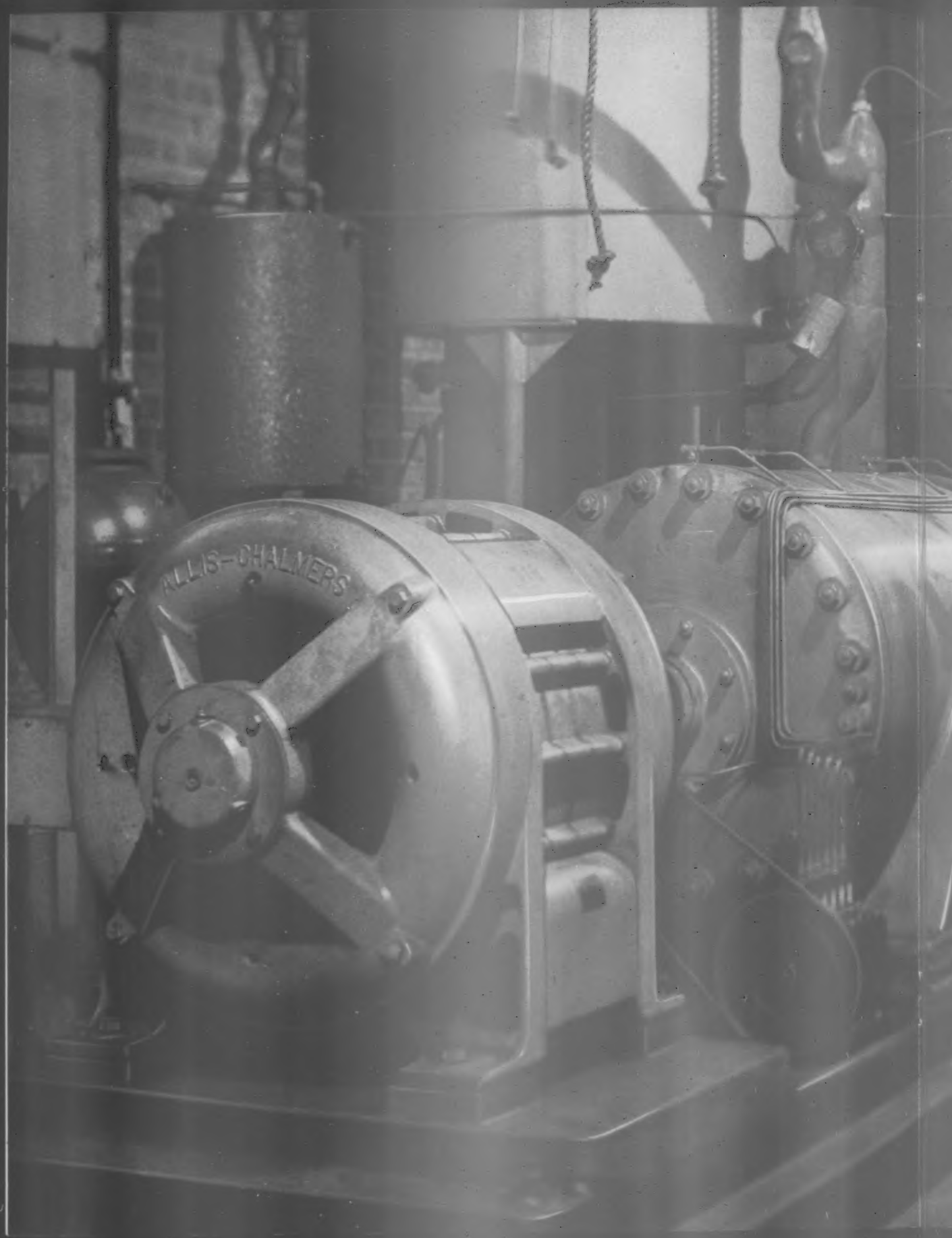
In addition to the modernization work done in the factory, new 115 kv oil-filled bushings and new bushing current transformers were applied to the breaker. Hence, every part of the breaker was either modified or replaced and when the breaker was reinstalled, it was completely modernized in the strictest sense. Again, the overall cost of such a complete modernization necessarily approximated (and in similar cases may even exceed) the cost of a modern breaker of equivalent rating.

Conclusion

The interrupting capacity or the interrupting performance of most obsolete oil circuit breakers may be considerably improved by modernization. The changes necessary to achieve a desired improvement in circuit breaker performance depend upon the adaptability of the original design to the application of modern parts, and upon the degree of improvement desired. Result is, the cost of modernization also depends upon these two factors.

Consequently, since a modernized breaker will sometimes provide all of the essentials which a modern breaker will provide, and since the cost of modernization may be appreciably lower than the cost of a new replacing breaker, it is always advisable to give due consideration to the possibility of modernizing, instead of replacing, an obsolescent breaker.

AIRCRAFT CARBURETOR TESTING (on following pages) — an important operation in tremendous wartime production — involves more than 100 rotary vacuum pumps and motors in this one installation. One or more pumps are used to simulate rarified atmospheric conditions in chambers where the carburetors are tested for leaks and performance efficiency.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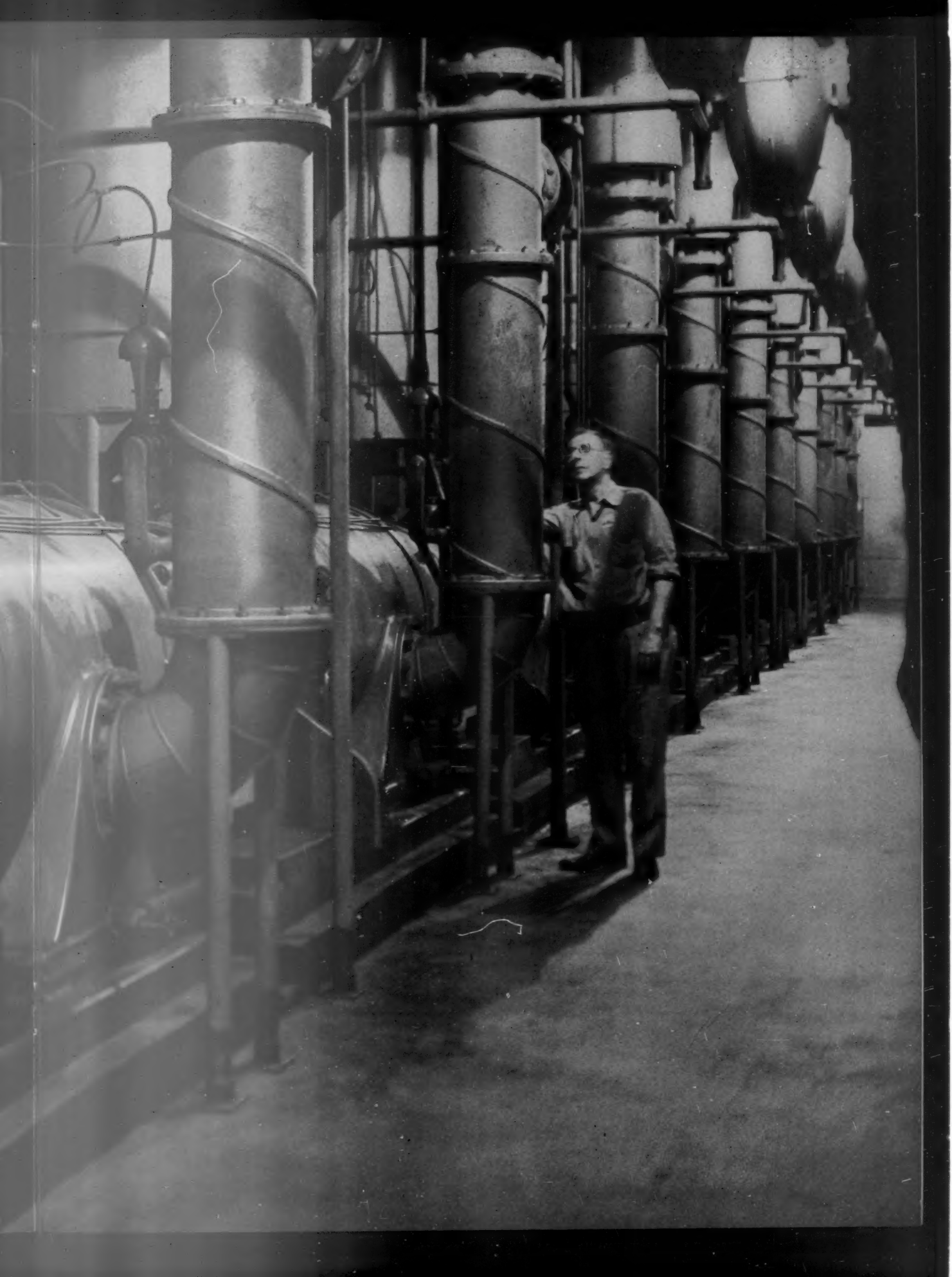


Mastering the *Short Circuit*

DR. KARL LERSTRUP
Switchgear Section,
Allis-Chalmers Manufacturing Company

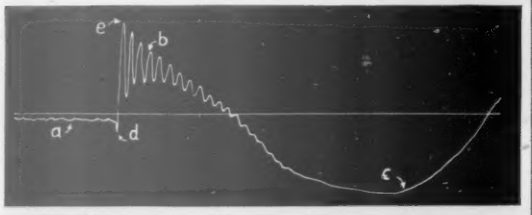
COUNTLESS TESTS in special laboratory facilities precede actual application of switchgear in the field. Here a newly designed circuit breaker is being operated in a series of tests simulating all possible service conditions.

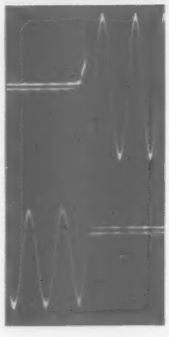
WHAT happens in the split-second flash when the most dreadful of electrical faults, the short-circuit, is successfully dealt with by modern switchgear? Here is the newest revelation of this electrical phenomena.

PRACTICALLY all circuit interruptions are accomplished through the medium of the electric arc. Contrary to common opinion, the arc is not a necessary evil which has to be fought by all available means. Rather, the electric arc should be considered a convenient help in performing the difficult task, although one which must be very carefully controlled and guided so that it can safely and efficiently accomplish its various duties.

The method of applying the electric arc in circuit-breakers, therefore, varies a great deal according to which duties the respective breakers are intended to perform. Thus the major problem of interrupting a direct-current circuit consists of *reducing the current to zero value*, while this problem naturally is of little significance in an a-c circuit. Here the important task is to *maintain the current at zero value.*

This problem is easier to understand when we have realized just what the situation is in an alternating-current circuit at the moment the current passes its zero value. We know that for each instant the voltage-drop in the circuit must be equal to and opposite the voltage induced in the generator. We realize, therefore, that we can forget about the resistance because the voltage drop in the resistance is proportional to the current, which we have just assumed to be zero. However, the self-inductance of the circuit gives a voltage drop which is proportional to the





INTERRUPTION SEQUENCE, taken from an actual cathode-ray oscillogram of voltage across a pair of contacts, includes (a) rather irregular arc-voltage, (b) recovery oscillation, (c) voltage induced in generator as oscillations gradually die out. At peak of arc-voltage (d), current stops flowing in the arc, but continues to flow in circuit through the capacitance until high peak (e). **(FIG. 1).**

CURRENT OSCILLATIONS, as well as oscillations in recovery voltage created by charging of circuit capacitances, are seen in this oscillogram. **(FIG. 2).**

rate of change in the current and, since in this connection we can generally neglect capacitance, we realize that the *rate of change* in the current at its zero passage is solely determined by the *voltage* induced in the generator and by the *self-inductance* of the circuit.

Circuit conditions simplified

As an experiment, assume that it is possible to separate the breaker contacts infinitely quick and in the exact instant the current reaches zero, and that the current then remains zero. Now there is neither current nor change in current and therefore no voltage drop in the circuit and the entire induced voltage from the generator must be present between the contacts. In other words, at the moment the interruption takes place the voltage between the contacts suddenly jumps to a value equal to the simultaneous value of the voltage induced in the generator, which is also the terminal voltage at no load.

The above simplifications, however, are carried a little too far. The contacts with their leads and other structural members constitute a certain capacitance. Therefore, even if we do separate the contacts instantaneously and in the exact moment the current reaches zero, the current will not remain zero, but for a very short time it will continue to flow in order to charge this capacitance; and since this capacitance is charged through the self-inductance of the circuit, the current will not cease until the capacitance is charged to almost double the voltage induced in the generator. Then the current will reverse and discharge again, almost to zero, and thus through a series of oscillations the voltage across the contacts will finally reach the value of the induced voltage of the generator.

This conception is still highly idealized and many factors tend to modify it, but whatever the situation, the general picture remains: *after the interruption the generator voltage is established across the contacts through some kind of oscillation.*

In most practical switchgear the contacts may separate at any odd moment in the current cycle. Then, usually, an arc is established between the contacts through which the current continues to flow until it reaches a zero point. Next, the arc goes out and the generator induced voltage will be established between the contacts as we have seen. However, it may very well be that the insulation between the contacts is not good enough to stand this voltage and presently the gap breaks down and a new arc is formed. The new arc will carry the current until another zero point is reached and another interruption attempt can be made and so on until the interruption is successful.

Kinds of break-downs

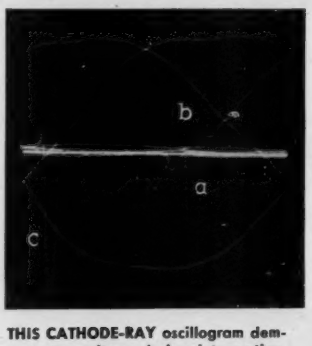
Such a break-down of the gap between the contacts immediately after a current zero is termed a *"re-ignition"* and when not too frequent it is a natural phenomenon for many types of switchgear.

After the generator voltage is successfully established over the contacts, it may also happen that the contact-gap suffers a set-back in dielectric strength, or that the next half cycle of voltage is extra large due to certain circuit conditions. Then the gap between the contacts may again break down, and this kind of a break-down is called a *"re-strike"* and can be characterized by a definite *interval of zero current* preceeding the break-down.

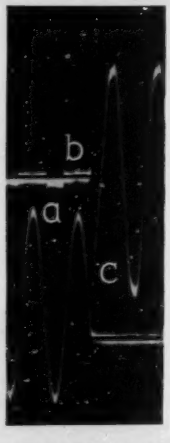
Such re-strikes are always undesirable and require corrective measures.

A third possibility is that a break-down takes place not between the contacts, but at a place where it was never intended that any arcing should occur. Such a break-down is usually termed as "flashover", and should never happen on well designed switchgear.

We have seen that the generator induced voltage is established across the contacts through an oscillation. The character of this oscillation, especially the rate of rise of the first part may have a significant in-



THIS CATHODE-RAY oscillogram demonstrates voltage during interruption. Electron beam, moved from left edge to right edge, jumped back to left edge at same height, moving across again and again. In this modern oil circuit breaker, arc voltage was very low compared to generator voltage. At first current zero passage (a) voltage rises steeply, but insufficient dielectric strength causes re-ignition and starts a new arc. Half cycle later a second interruption attempt fails (b), and there's another re-ignition. After another half cycle, interruption is completed (c). **(FIG. 3).**



SAME INTERVAL of interruption on ordinary oscillogram clarifies sequence showing (upper trace) voltage across contacts; (lower trace) current flowing in circuit. **(FIG. 4).**

OIL CIRCUIT BREAKER has contacts separated under oil, which cools the arc through evaporation and chemical decomposition, which consumes a great amount of arc energy. Hydrogen, product of decomposition, is best arc-cooling medium known. Ruptors guide and control arcs and cooling forces. **(FIG. 5).**

AIR BLAST BREAKER, ideally suited to repetitive duty, utilizes extremely short arc length and cooling of a heavy blast of air. It is most effective around instant when current passes through zero. Ideal interruption conditions are just as contacts part; interruption is complete first time current reaches zero value. **(FIG. 6).**

MAGNETIC AIR BREAKER employs a heavy magnetic field to push arc up into the arc chute, where it is thrown against a multiplicity of ceramic barriers. Arc is thereby cooled and prepared for its final extinction. This type of breaker is very popular because of simplicity, oil elimination, and reduced fire hazard. **(FIG. 7).**

fluence upon the possibility of reignition or completed interruption. While the current flows the arc forms a conducting path. In order to prevent reignition this path must be transformed into an insulator strong enough to stand the voltage across the gap and this transformation must take place so fast that the dielectric recovery of the gap is always ahead of the rise of the voltage.

We have thus revealed two distinct means of attacking the circuit breaker problem. We can make provisions which insure a very high rate of dielectric recovery and we can make provisions with the aim of reducing the rate of rise of the voltage across the contacts.

The rate of rise of the voltage is mainly determined by the instantaneous condition of the circuit to be interrupted, a condition which is usually outside the control of the breaker manufacturer. It is possible, though, to incorporate certain features in the breaker design which tend to modify the circuit conditions in the moment of interruption, but the external factors remain very significant and must be considered in each case to insure the desired results.

It is little wonder, therefore, that the concerted effort of most designers has been towards improving the dielectric recovery.

Improvement of dielectric recovery

From the foregoing it appears natural that the crucial moment in the interruption is the very short interval during which the potential difference between the contacts increases from zero to its maximum value. The signficance of this interval has been discussed frequently. According to some this is the moment to *substitute an insulating medium for the arc remnants* while others assert that the prime aim should be to *turn the very arc remnants into an insulator.* The difference between these two theories is not at all basic. The latter theory actually encompasses the first as a special case and is the same as that expressed by early writers who used the more prosaic, but equivalent term of *cooling the arc.*

However, the significance of *the interval just before the current reaches zero* is seldom appreciated, though the action in this interval is of a consequence equal to or even greater than that of the immediately following period. The appreciation of this will require a few words about the character of the arc and in particular the voltage across the arc.

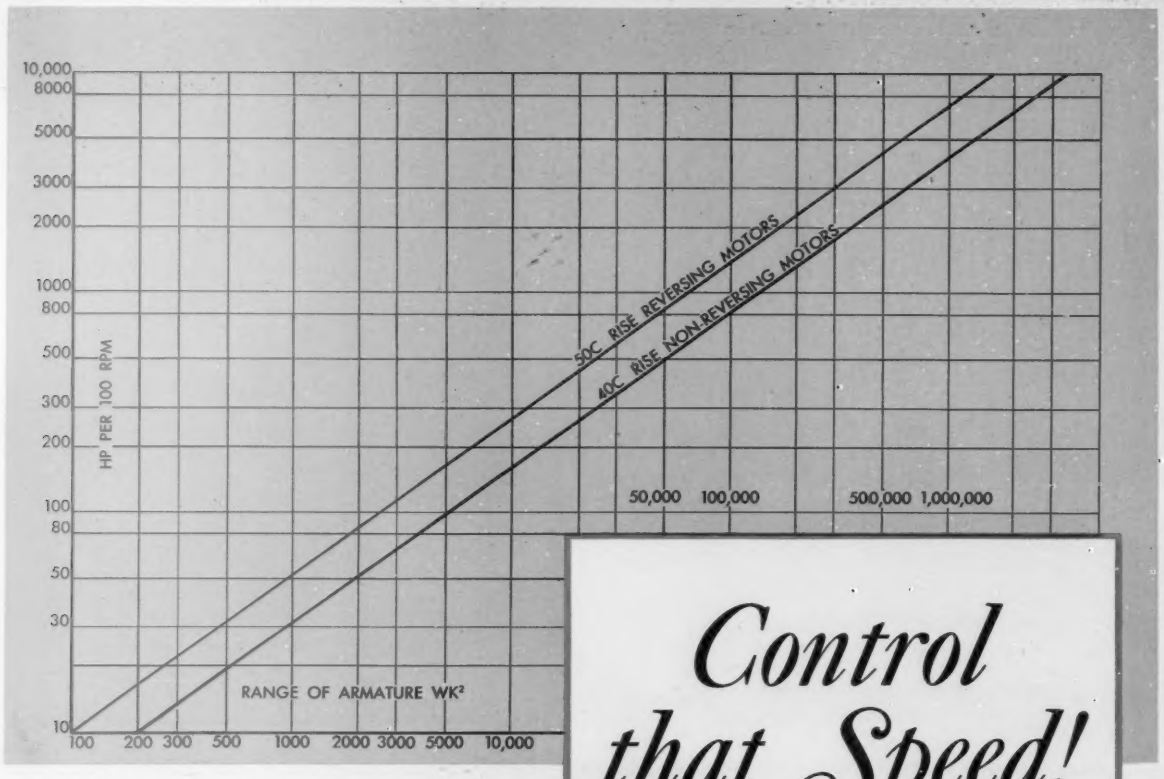
The arc voltage can be influenced through the design of the breaker in a great many ways. In general it is agreed that a high arc voltage is undesirable because it implies a large amount of energy dissipated inside the breaker, and this in turn calls for a heavy and expensive construction. (The exception is the extreme case where the arc voltage is made to become so high that it has a marked influence on the magnitude of the current, so much that the reduction in current outweighs the increase in voltage. This principle, too, has been successfully applied to breaker design.)

The current in the arc is conveyed by ions. A large voltage drop in the arc, therefore, can be caused either by a *scarcity of carriers* or by a *long, tortuous* path for the carriers.

It is common practice, therefore, to keep the length of the arc down to a minimum in order to avoid high arc-voltages due to mere length.

High arc voltage caused by scarcity of carriers is of much greater significance and very desirable when it occurs only at the *end of a period of conduction.* If we can design in such a manner that during the last part of a conducting period carriers are removed or recombined at a rate so much greater than the rate of production that we actually *reduce the number of carriers faster than the current decreases,* then we shall be in a very favorable position to produce a very rapid and permanent dielectric recovery.

Thus it is clear that the criterium for good breaker performance is to be sought in the events of the last moment *before a current zero point,* rather than after. To reach this goal in the shortest possible time and with the greatest certainty and safety are the major aims of the art of circuit breaker design, and the patent files are bristling with the greatest variety of ideas aimed at accomplishing these objectives. The only common features are means for separating a pair of contacts and provisions for cooling the resulting arc, otherwise the practical ways and means of accomplishing circuit interruption are legion.



RANGE OF ARMATURE WK² for direct-current motors is shown in approximate values for ratings from 10 hp per 100 rpm to 10,000 hp per 100 rpm. Variations in design standards will necessarily cause deviations. (FIG. 1).

Control that Speed!

PART II

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Motor and Generator Section,
Allis-Chalmers Manufacturing Company

DIRECT-CURRENT motors are leading variable speed device for reversible operation in variety of applications on locomotives and ships . . . in mines, mills and factories throughout industry

AMONG the types of large variable speed motors now finding increasing favor throughout industry, the direct-current motor for reversible operation is less widely applicable than the non-reversing type, yet quite indispensable in such diversified applications as metal-rolling mill stands, planer drives, mine hoists, elevators, railway locomotives, and ship propulsion service. Each has peculiarly distinctive characteristics which require the consideration of numerous interdependent factors in planning the design and operation of the drive.

For example, a metal planer drive of modern design provides speed ranges as high as 30 to 1 — an outstanding example of the maximum utilization of a combination of variable-voltage and motor-field weakening control. In a drive of this kind useful work is being done only with the planer platen operating in one direction; in the opposite direction the platen is merely moving back into position for the next cutting stroke. Provision, obviously, must be made so that the cutting speed may be set at the speed best suited to the material planed and the cutting tool used. However, on the return "idle" stroke, the highest practicable speed should be used to secure the least operational delay.

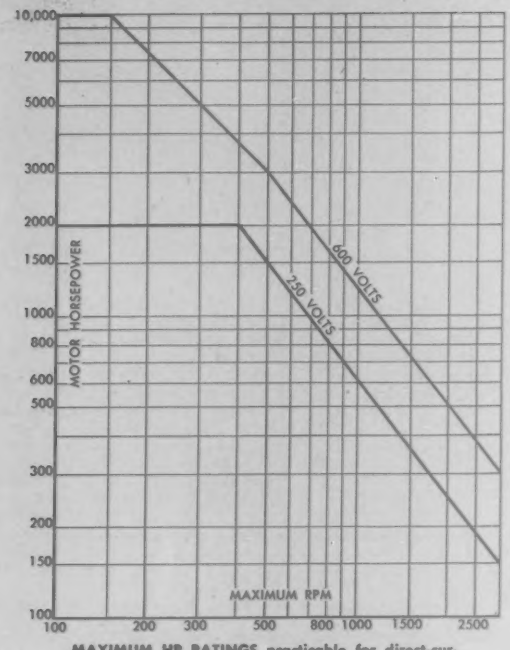
Similarly, in a reversing metal-rolling mill drive it is necessary that the motor be reversed, in the minimum time after each pass, to the speed providing the requisite torque for the particular pass and the reduction of the material being rolled.

Reversing motors, therefore, generally involve a need for rapidity of speed response, low inertia for reversal, and maximum torque for useful work. These requirements are in contrast to the paramount importance of fine speed regulation in many non-reversing motor applications.

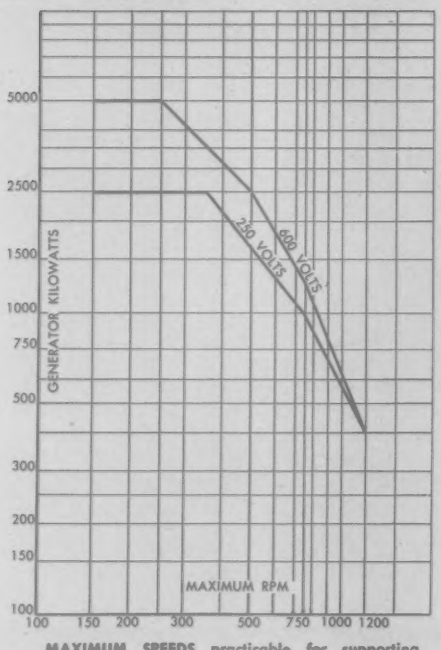
Armature flywheel effect

In designing non-reversing motors most economically and to obtain the maximum possible output consistent with the rated temperature rise and economic manufacturing considerations, the armature moment of inertia or flywheel effect is not particularly considered.

In the first part of this series on variable speed drives (December, 1944 Allis-Chalmers ELECTRICAL REVIEW), speed control requirements and methods were discussed generally. Alternating-current motors in variable speed applications will be treated in a future issue of the REVIEW.



MAXIMUM HP RATINGS practicable for direct-current motors at 600 and 250 volts for various motor speeds represent manufacturers' limits. (FIG. 2).



MAXIMUM SPEEDS practicable for supporting generators at given capacity output are also important factors in selection of a drive. (FIG. 3).

However, for large motors where frequent reversal is part of normal operation, the flywheel effect obtained by such normal design would originally be objectionable because of the power required to accelerate and decelerate the armature during the period of reversal. Also, the response to sudden change in speed setting would be slowed down.

Consequently, special design is utilized to modify motors for reversing service to reduce the flywheel effect as much as 50 percent of that for a normal non-reversing machine. Since the torque required for acceleration is a direct function of this flywheel effect (Wk^2), it is evident that this torque will be in direct proportion; or conversely, the time of reversal will be inversely proportional to Wk^2 for a given applied torque. Thus, either the time of reversal will be reduced or the torque available for useful work will be increased accordingly, as a result of special design for low Wk^2.

Figure 1 shows the approximate values of armature Wk^2 for 40 C rise non-reversing and 50 C rise reversing motors for a range of ratings from 10 hp per 100 rpm (for example, 100 hp at 1000 rpm) to 10,000 hp per 100 rpm (for example, 5000 hp at 50 rpm). The values shown are subject to variations by manufacturing standards which necessarily limit the number of diameters permissible for economic production, so that the change is not absolutely uniform. Values shown for reversing motors might be considered a minimum and not necessarily attainable for every case.

As is often the case in machine design, the attainment of one desirable characteristic leads to a sacrifice along some other line. In the case of low armature Wk^2 d-c motors, low speed motors will probably require forced ventilation because of reduced fan action available for normal ventilation.

Maximum ratings for d-c drives

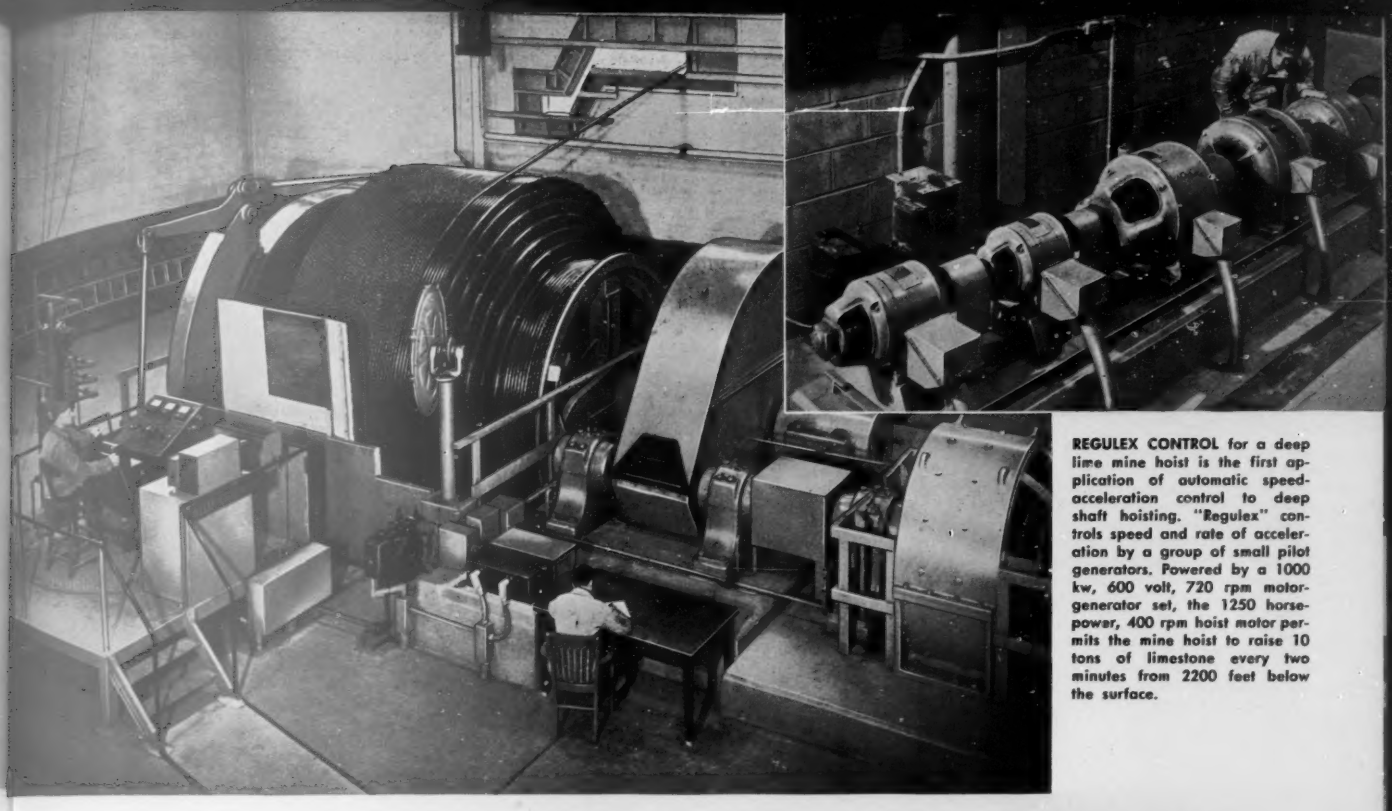
Direct-current drives do have certain limitations in capacity. Although these limitations do not usually interfere with their use for adjustable-speed drives, it may be well to indicate these limitations in order to explain why it is sometimes necessary to resort to other systems of drives.

Shown in Figure 2 are the approximate maximum horsepower ratings that it is practicable to build for various motor speeds, at 600 and 250 volts. For 250 volts the problem of current capacity and commutation imposes a much lower limit than for 600 volts, and, while ratings as high as 2000 hp are shown, it has generally become the practice to resort to higher voltages for ratings over 500 hp because of the savings in control and feeders.

Nevertheless, where a limit is indicated for any particular single machine rating or speed, double armature combinations may be permissible. For example, if it is conceivable that a 4000 hp 300/500 rpm rating should be required, we find from Figure 2 that the maximum horsepower at 500 rpm is 3000 hp. But it may be possible to use two 2000 motors to make a double armature unit, depending upon the nature of the load and the arrangement of the supporting generators.

In connection with double armature motors, it is generally desirable to have the armatures operate in series to obtain proper load equalization. Under certain conditions it is permissible to use parallel operation, achieved by using a cumulative series and a differential series on each machine. The differential series of one machine carries the armature current of the other to obtain fairly good equalization of load. However, it also introduces complications in the control and should be avoided wherever possible. Where two generators, as on a motor-generator set, support a double-armature motor, it is also possible to use a "sandwich" arrangement. This, in essence, is a series system which limits the voltage to ground to that of the rated generator or motor voltage.

The supporting generators are likewise limited by maximum practicable speeds for a given capacity out-



REGULEX CONTROL for a deep lime mine hoist is the first application of automatic speed-acceleration control to deep shaft hoisting. "Regulex" controls speed and rate of acceleration by a group of small pilot generators. Powered by a 1000 kw, 600 volt, 720 rpm motor-generator set, the 1250 horsepower, 400 rpm hoist motor permits the mine hoist to raise 10 tons of limestone every two minutes from 2200 feet below the surface.

put, as indicated by Figure 3. Hence, cases may arise where a motor may readily be built but the cost of the supporting generators and their prime movers may make the overall cost prohibitive. As an exaggerated case, a twin screw ocean-going ship drive requires 7350 hp per screw at 130 rpm, each motor being supported by two 3000 kw generators. The speed of the generators could not exceed 400 rpm (from Figure 3) if they were geared steam turbine driven, or perhaps 200 or 225 rpm if they were diesel-engine driven. In either case, a rather expensive generating unit would result. In a case of this kind it may be logical to assume that the advantages of the d-c drive would be more than offset by the much lower cost of a synchronous drive.

In the case of a drive such as a variable torque, adjustable speed unit rated 500/2000 hp 900/1800 rpm, it is evident from Figure 2 that this is well beyond even a double-armature d-c drive. Here the d-c machine still plays an important role, although a different system of drive must be employed.

However, in the case of a reversing metal-rolling mill, such as a blooming or slabbing mill, no alternative drive can provide the speed control and time of reversal necessary to the economical operation of such a mill. Where the motor is of exceptionally large size, it is generally necessary to resort to two generators in order to keep the speed of the supporting motor generator set to an economical value.

Speed regulation factors

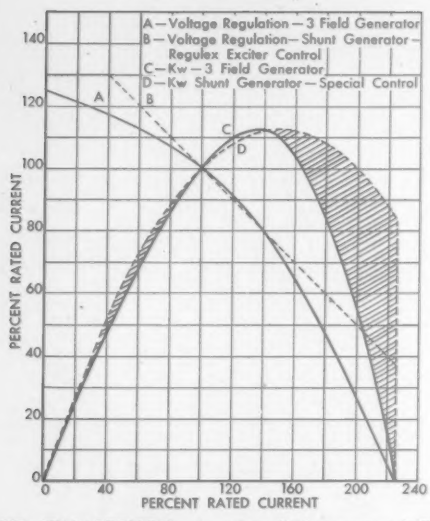
In considerations of speed regulation — the difference between the steady full-load speed and the steady no-load speed, expressed as a percentage of the full-load speed, with constant terminal voltage applied to the motor — it is always understood that guarantees of percentage speed regulation apply to "steady state" conditions. When the load is applied or relieved very suddenly, the change in speed may momentarily exceed the given values. This momentary fluctuation is inherent in any d-c machine, but experience has shown that it ordinarily causes no trouble when in operation.

For adjustable-speed drives, we are concerned principally with motors which are basically shunt wound. The speed regulation of a shunt wound motor is dependent upon the IR drop in the armature circuit (i.e., in the armature winding, the interpole winding, the series stabilizing winding, and in the compensating winding, if used), and upon the armature demagnetizing effect on the main field. In a high-speed, pure shunt-wound motor, the speed regulation curve generally tends to rise from no-load to full-load. That is, the increase in speed due to armature demagnetization of the field is somewhat greater than the decrease in speed due to IR drop. Because such a rising speed characteristic is usually undesirable for adjustable speed drives, the series stabilizing winding previously mentioned is added to stabilize the magnetic field and its added IR drop tends to flatten out the speed regulation curve.

Likewise, in large motors requiring compensating windings to overcome armature reaction, the effect of compensation results in a more nearly constant field flux and with the added IR drop approaches a more nearly flat speed regulation curve. The IR drop is also a function of speed, the IR drop in a low speed machine being greater for a given horsepower rating than in a high speed machine.

Because of the complexity of application requirements, it is not possible to cover here all of the regulation possibilities for the complete range of horsepower ratings and speeds. However, the following tabulation gives an indication of normal inherent speed regulation guarantees for metal-rolling mill service motors of ratings over 200 horsepower:

Speed Range	Percent regulation with maximum (weak-field) speed	Percent regulation with minimum (full-field) speed
2 to 1	2	4
3 to 1	2	6
4 to 1	2	8



OPERATING CHARACTERISTICS of a three-field generator indicate that maximum power requirement is 112½ percent of rated load. (FIG. 4).

Note that the regulation at minimum (full-field) speed is the product of the maximum (weak-field) speed regulation and the ratio between maximum and minimum rated speeds. For example, if the speed range is 300 to 600 rpm, the speed regulation at 600 rpm is 2 percent or 12 rpm, at 300 rpm it is 4 percent or also 12 rpm. For voltages in the range of 100 percent down to 50 percent the speed regulation will increase approximately in proportion to the reduction in voltage. Hence, if the motor is operated as a constant current, constant torque machine down to 150 rpm at 50 percent voltage, the speed regulation at that point would be 8 percent, or 12 rpm. Motors above 200 hp for ordinary commercial service will generally have inherent speed regulation about 50 percent higher than those indicated above.

Because of the factors involved, perfect (zero percent) speed regulation is not possible in a d-c motor. Better regulation than indicated above can of course be provided in large machines for special purposes, but only at an increase in cost to cover the necessary refinements in design. These might even include the use of larger than normal frames. However, the finer and final degrees of speed regulation will ordinarily be taken care of in the control, which can readily compensate for IR drop if made responsive to voltage drop across one part of the armature series circuit, as for example across the interpole winding. The use of devices with high-speed response, such as the high amplification factor Regulex exciter and/or electronic tubes, have successfully answered this problem.

Three-field generators

Use of the direct-current system often allows certain other desirable characteristics to be built into machines to accomplish a specific purpose. A noteworthy example of this is the "three-field generator" commonly used in well drilling service, electric shovels, drag lines, blooming mill auxiliaries, and similar applications.

The primary purpose of this generator is to limit the maximum torque developed by the motor and also to limit the power demand on the generator's prime mover, which is usually a Diesel engine. The three-field generators, as the name implies, are built with three-field windings—one a self-excited shunt winding, one a separately-excited shunt winding, and the third a differential series winding.

The operating characteristics of a machine (Figure 4) show that the maximum power requirement demanded of the engine will be about 112½ percent of rated load. If in this case the torque demand of the d-c motor requires a current flow of greater than 135 percent, the voltage of the generator will decrease rapidly enough to prevent the power requirement from exceeding the maximum value. Actually, at high current points the voltage drops to a value low enough to allow operation at very high torques, while staying well within the power limits of the prime mover.

A second major advantage in this type of drive is the characteristic of limited maximum torque on the motor. If the torque demand of the load exceeds the predetermined value of maximum torque of the motor, the motor will stall at the maximum value, thereby effectively preventing breakage or mechanical damage to the equipment driven by the motor.

A third advantage lies in the fact that when light torques are required by the load, the generator voltage rises above rated value. This feature allows rapid time-saving operation under light loads, such as an empty block being raised or lowered on an oil well drilling rig.

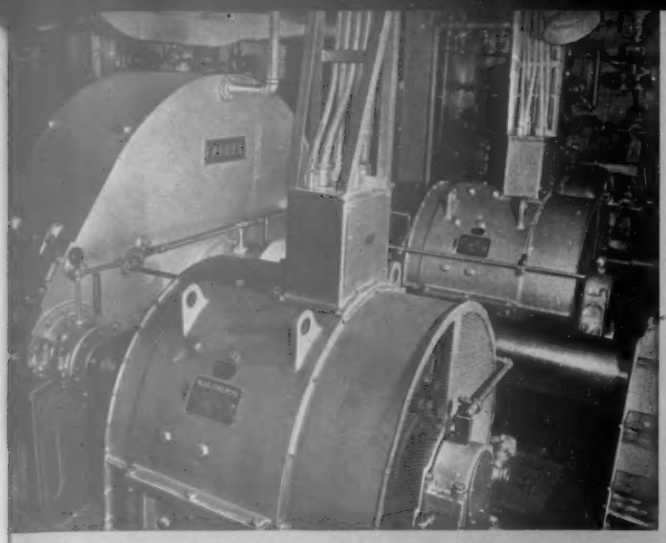
A disadvantage of the scheme is the fact that, especially on heavy load points, the power capacity of the engine is not utilized to its maximum value. For instance, at 200 percent current on the generator (which indicates approximately 200 percent torque on the motor), only 56 percent of the power capacity of the engine is being used. Modern methods of control can minimize this effect.

Combine generator, exciter

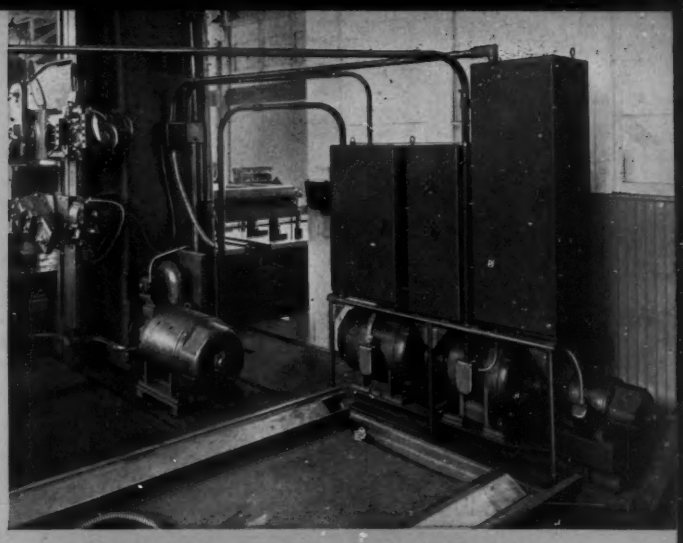
The characteristics of the three-field generator can be simulated, in fact actually improved upon, by the use of a straight shunt-wound generator working in combination with a rotating type regulating exciter having special field characteristics and high-speed response. One reason for the use of such a combination is that, depending upon maximum torque and stalling current permissible, the three-field generator may be from one to two frame sizes larger than for the standard shunt-wound machine.

Another advantage indicated by Figure 4, dotted curve, shows the characteristics which can be obtained with this scheme. The power curve (D) of the shunt-wound generator is much broader and therefore provides a much wider range in which the prime-mover can exert a large percent of its capacity. For example, again taking the 200 percent current point, the engine can now deliver 100 percent of its rated power. Therefore, the entire area covered by the cross-hatching is gained in actual power output available from the set-up.

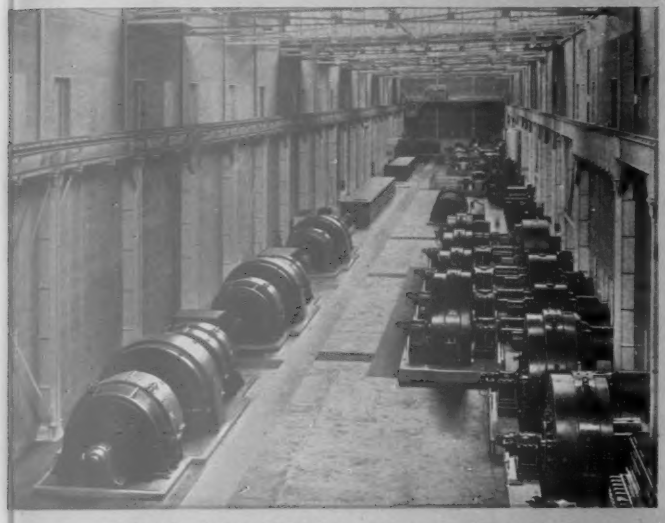
It must be borne in mind that the values above normal rated values are limited in time by the thermal capacity of the machines as well as their ability to commutate the currents involved. For example, if 225 percent of rated amperes is required for any particular application, the motor and generator will usually be designed to carry this current for a period of one minute. Any current demand less than 225 percent and in excess of 100 percent can usually be safely carried for a period of time varying almost inversely to the loading in excess of 100 percent.



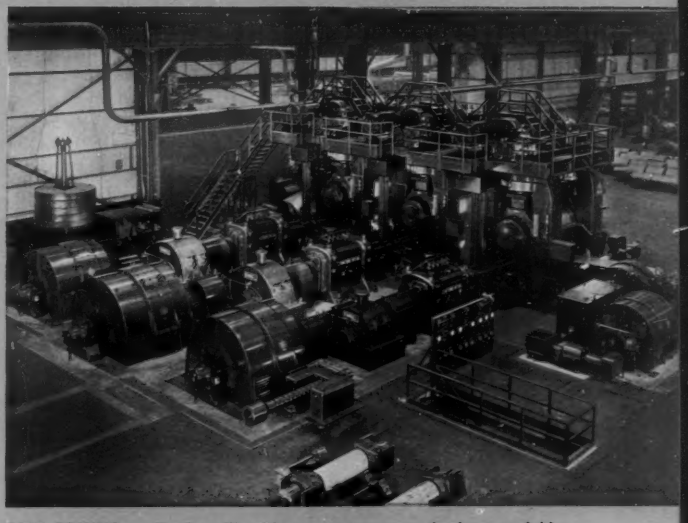
SHIP'S MOTOR ROOM has two high speed motors on each side of a large reduction gear through which they drive the ship's propeller shaft.



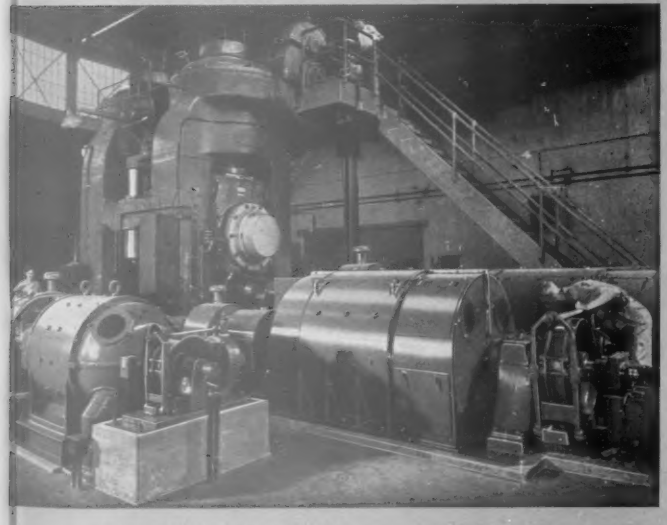
ULTRA-SPEED PLANER DRIVE, rated 30 horsepower, is representative of the type of application particularly suited to variable voltage direct-current drives.



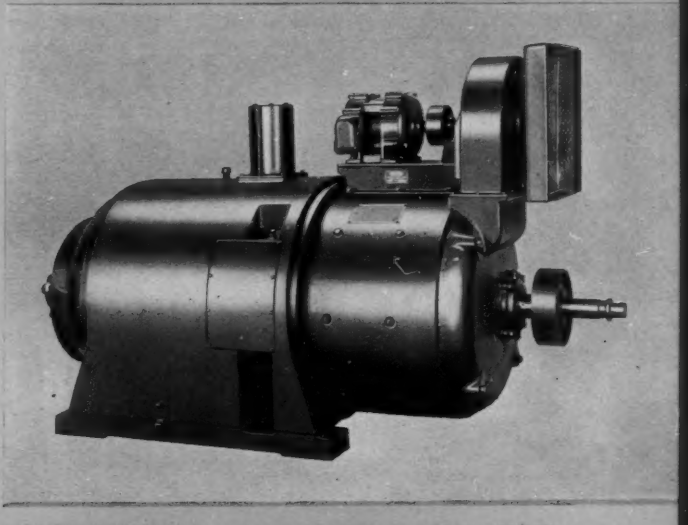
STEEL MILL MOTOR ROOM for a 96-inch strip mill houses this array of direct-current motors and their supporting motor-generator sets. Reversible operation of the big machines makes them indispensable for this service.



STEEL ROLLING applications like this are most common for large variable speed drives. The three-stand tandem cold mill is driven by motors rated 800 to 3500 hp, all under variable armature voltage control.



COLD ROLLING MILL has 150 horsepower, 400/1200 rpm d-c motor (at left) for reel drive and a 500 hp 200/500 rpm d-c motor driving tension rolls.



DRAG-REEL GENERATOR for a temper pass mill is rated 25 kw, 400/1600 rpm, and is complete with gear unit and frame-mounted blower and filter.

What a Power System Needs to be "*Effectively Grounded*"

V. J. CISSNA and W. C. SEALEY*

U. S. POWER systems being predominantly "solidly grounded", proper selection and application of the grounding transformers is an all-important problem, and the simplified method presented here helps to solve it.

ALTHOUGH there are a few isolated neutral systems and an increasing number with neutrals of transmission systems grounded through tuned neutral reactors, the power distribution systems of the United States are predominantly "solidly grounded." On the lower voltage transmission systems and on the primary distribution systems, grounded neutrals are frequently supplied by means of delta-wye or zigzag grounding transformers the sole purpose of which is to convert an otherwise isolated neutral system into a grounded neutral system.

Grounding transformers are special and their functions should be clearly understood in order to apply them properly. The simplified method offered here describes selection of proper size and characteristics and explains their limitations and operation. Grounding transformers, to begin with, perform three main functions:

1. They hold the neutral shift within limits which will not permit voltages that can cause damage to connected equipment.
2. They permit the circulation of unbalanced load current in the neutral of four-wire primary distribution systems.
3. And they make possible the circulation of ground fault current for the operation of protective relays.

The first two functions are those associated with systems having "solidly grounded" neutrals, while the third may be associated with any degree of grounding from "solidly grounded" to essentially isolated neutral operation having only sufficient ground fault current to operate sensitive ground relays, in which case the system would not be suitable for four-wire primary distribution service. Figure 1 illustrates the action of grounding transformers in permitting the circulation of current through their neutrals. If a short circuit to neutral should occur on phase 3, the short circuit current would have the same relative distribution.

The term "solidly grounded" has been generally accepted to mean that all neutrals of the supply transformers on a system have been grounded by means of connections having no intentional impedance. Since systems using grounding transformers obviously cannot comply with the generally accepted definition of solidly grounded neutral systems, an equivalent standard is needed. The American Standards Association definition (35.15.205) for "effectively grounded" systems covers the requirements which must be met and which are those ordinarily associated with systems having "solidly grounded" neutrals. It states that "effectively grounded means grounded through a ground connection of sufficiently low impedance (inherent and/or intentionally added) that fault grounds which may occur cannot build up voltages dangerous to connected equipment."

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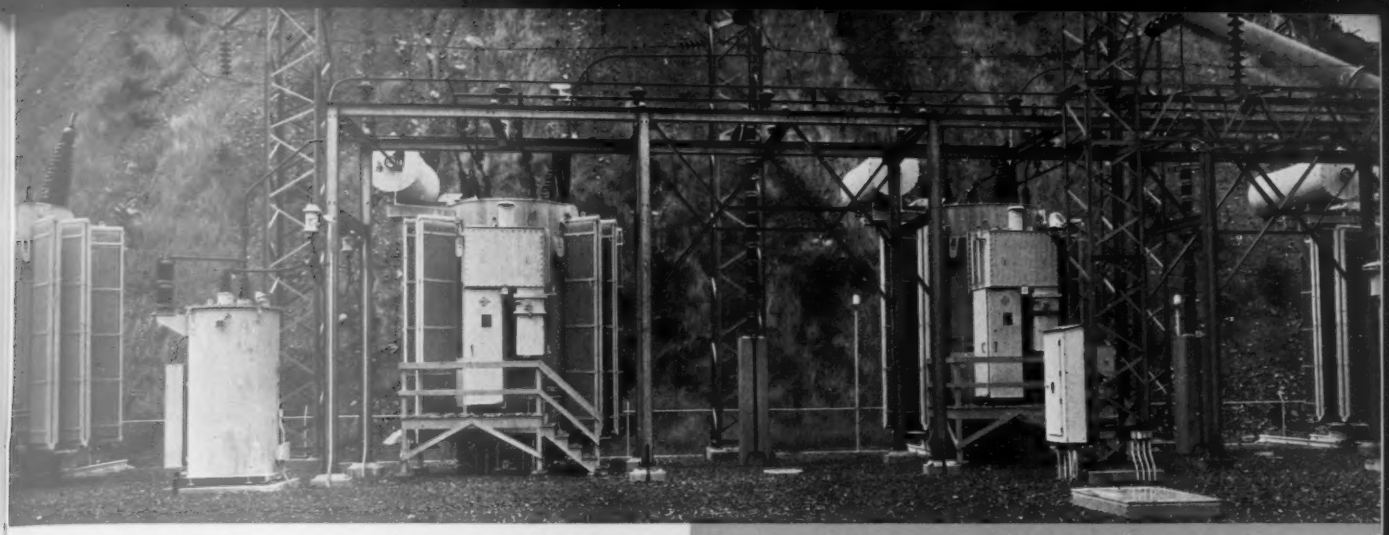
Since "solidly grounded" neutral systems frequently do not hold fault voltages within safe values, it is the authors' opinion that the term "solidly grounded" should be discarded and the term "effectively grounded" used in its place. However, there is no official standard defining specifically the electrical characteristics of an "effectively grounded" neutral system and the engineer must be his own judge in this respect. The makers of lightning arresters have decided to recognize as "solidly grounded" those systems which maintain ratios of zero phase sequence reactance to positive phase sequence reactance (Xo/Xp) of not more than three at the point of application of the arresters. With a ratio of Xo/Xp of three, the maximum voltage on an unfaulted phase during a fault to ground will seldom exceed 130 percent of the normal (rated) line to neutral voltage. Some authorities say that the ratio should not exceed two. This method should be qualified by the statement that the positive phase sequence reactance and the negative phase sequence reactance are equal and that X/R ratios of all sequence impedances are approximately the same. The Xo/Xp ratio method of defining a "solidly grounded" neutral system when used with full knowledge of all qualifying factors has proved entirely satisfactory in establishing "effectively grounded" neutral systems.

With the application of the method of symmetrical components to the solution of unbalanced current flow in polyphase systems, the selection of the proper size and characteristics of grounding transformers is now quite simple, once the purpose of grounding is decided.

Effectiveness of neutral grounding

One large power system uses the curves of Figures 2 and 3 in determining grounding transformer impedances, neutral reactor values, and lightning arrester voltage ratings. The curves of Figure 2 show voltages on good conductors together with sequence voltages at the point of fault for one-conductor-to-ground and two-conductor-to-ground faults as a function of Zo/Zp when all sequence impedances have the same X/R ratios and Zp=Zn. (Zp, Zn, Zo are positive, negative, and zero sequence impedances respectively.) The curves of Figure 3 show good conductor voltages for single - conductor - to - ground faults as functions of



FOR GROUNDING its 161 kv and 66 kv system, a Southern utility uses this bank of three-winding power transformers with load-ratio control. At left of this grounding transformer installation is a grounding reactor.

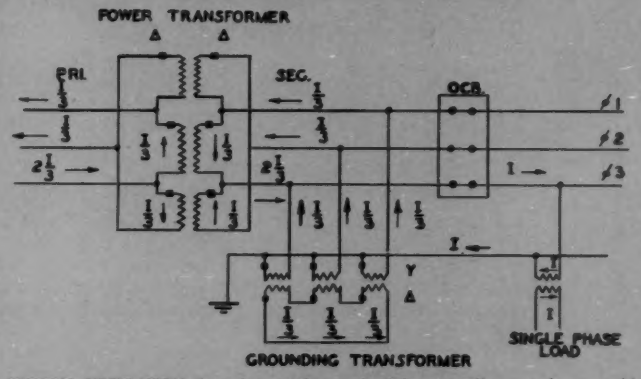
Zo/Zp and of the angle of departure of the positive phase sequence impedance from the zero phase sequence impedance. The angle of departure as here used is defined as the difference of the sequence impedance angles ($\phi_p - \phi_o$).

In making use of the curves it is the voltage rise on a good conductor and not Zo/Zp which is the determining factor, with 125 percent considered to be the maximum allowable momentary dynamic voltage on a system classed as "effectively grounded."

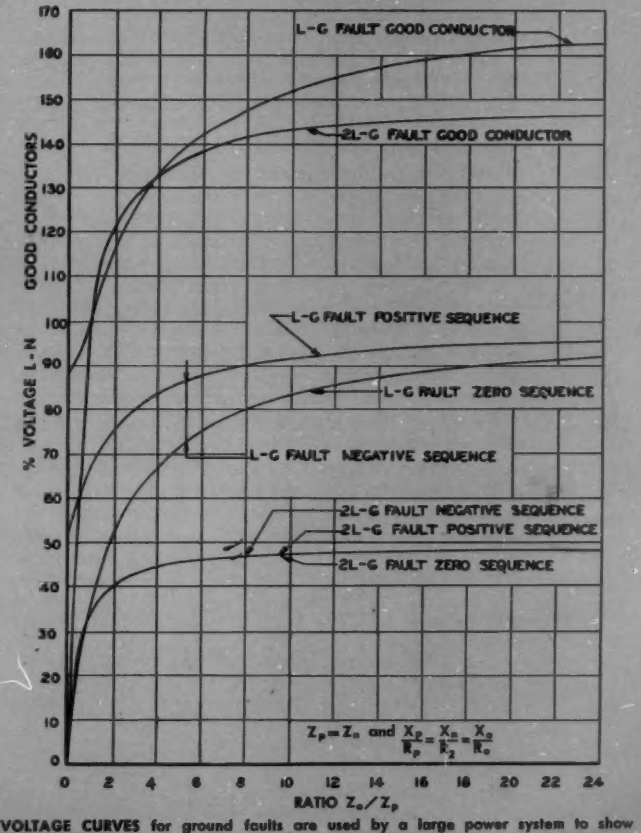
The 125 percent figure is based on normal voltage existing at the time of fault, which allows a margin of as much as 15 percent for over-voltages due to loss of load or other causes before lightning protective equipment begins to be in danger. Double-line-to-ground fault voltages are not affected by sequence impedance angle differences, as are those of single-line-to-ground faults, so that the curves of Figure 3 will control if there is an appreciable angle of departure between the positive and zero sequence impedances. Fault resistance is assumed negligible. The curves of Figure 3 hold true both for leading (plus) and lagging (minus) angles of departure, the only difference being that for plus angles, the phase leading the faulted phase will have the high voltage and for minus angles the phase lagging the faulted phase will have the high voltage.

Similar sets of curves can be drawn for other ratios of Zp/Zn, but they usually are not necessary. When wide differences between Zp and Zn exist, special calculations should be made. Differences of 10 percent between Zp and Zn will not invalidate the curves in the lower ratios of Zo/Zp but in the ratios of Zo/Zp above 5 allowable differences may be much larger. Loads have little effect upon the ratios but on four-wire three-phase systems loads will reduce somewhat the voltage rise on unfaulted conductors. In general, both loads and line capacitance can be neglected although exceptions require detailed studies.

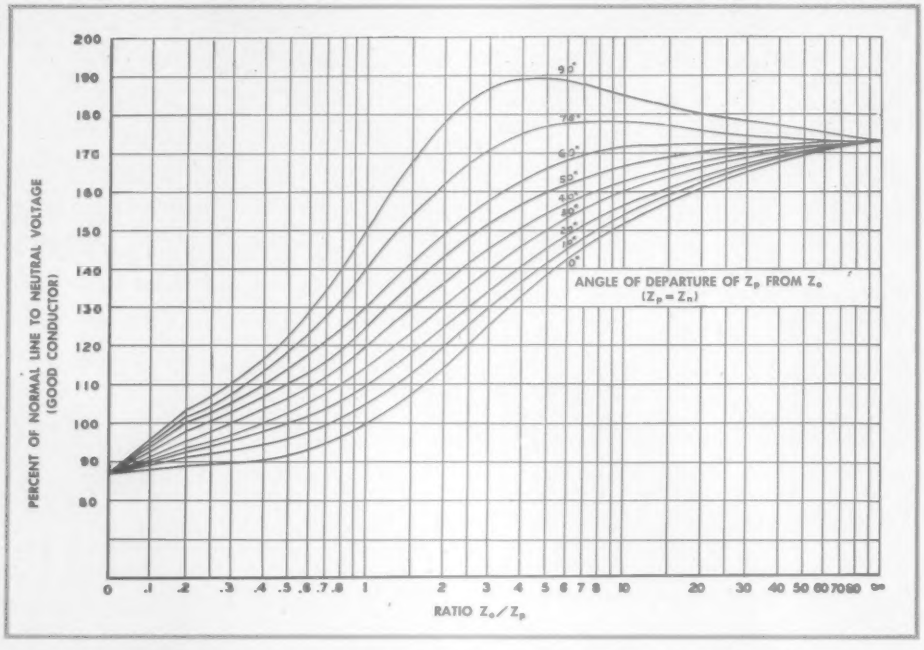
Fault resistance can cause an additional rise of potential under some conditions. However, Zo/Zp ratios must be low and the circuits highly reactive for any appreciable rise to be experienced. There appear to be no instances in the normal range of effectively grounded neutral systems, as determined by the methods of this article in which the rise can cause trouble. In the application example given later, fault resistances of 1 to 4 ohms cause up to 2 percent more voltage rise



CURRENT CIRCULATION through neutrals permitted by grounding transformers with a single phase load is illustrated in this distribution system diagram. (FIG. 1).



VOLTAGE CURVES for ground faults are used by a large power system to show voltages on good conductors and sequence voltages at point of fault. (FIG. 2).



VOLTAGES for single, line-to-ground fault are function of Zo-Zp and angle of departure of the positive phase sequence impedance from the zero phase sequence impedance. (FIG. 3).

than is shown by the curves of Figures 2 and 3. Fault resistances of greater magnitudes will reduce the voltage rise.

Neutral resistance on the other hand may cause a serious increase in the fault voltage on one of the good conductors, since it can cause a wide angle of departure if the Zo/Zp ratios are low and the sequence impedances are predominantly reactive. Resistance in the neutral must be a negligible part of the total impedance used in fault calculations in order that its effect on fault voltage will not be dangerous. The curves of Figure 3 evaluate effect of neutral resistance.

Grounding transformer design

In order to reduce their size, grounding transformers are designed to carry fault currents for only short times, common time ratings for grounding transformers being 10 seconds and 60 seconds. Common time ratings for fault currents for transformers whose principal function is to carry load current are from 2 to 5 seconds, the time rating depending upon the inherent reactance of the transformer. In actual practice, relays are provided which open the power circuits before this time is exceeded, in order to prevent injury to the transformer and other parts of the circuit.

Standard temperature limits have been established for various classes of grounding service. For ratings of 2 minutes and less, the assumption is made, for purposes of standardization, that all heat generated in the copper of the windings on short circuit is used to raise the temperature of the copper. (Actually the temperature rise is much less because a considerable quantity of this heat is absorbed by the insulation surrounding the copper.) The formula which expresses the relation between temperature rise and time when all heat generated is absorbed by the copper is:

Temp. rise above To =

$$2\ At\left[(1+At)\ (To+234.5)+\frac{309\ E}{1+At}\right]$$

Where To = initial temperature in degrees C; t = time in seconds; $A = 2.3 \times 10^{-11} \times$ (amps/sq in)^2; E = ratio of eddy current loss to I^2R loss (at 75 C).

An average value of E may be obtained from the certified test sheet of the transformer by taking the ratio of the difference between the wattmeter copper loss and the I^2R loss, calculated from the current in the winding and the measured resistance, to the calculated value of I^2R loss.

Standard temperature values

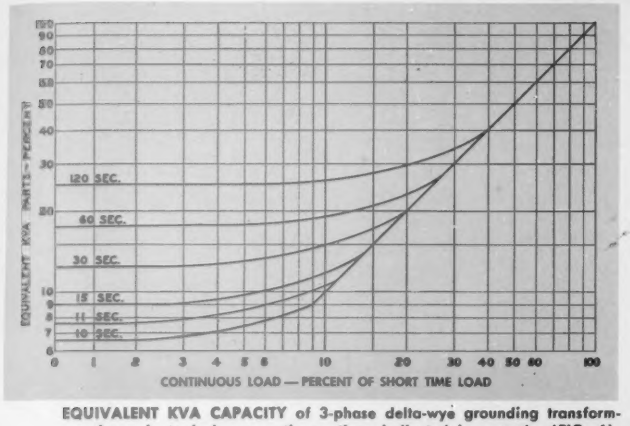
The three classes of grounding service are feeder fault protection, apparatus fault protection, and power transformation combined with fault protection.

Following are the standard temperature values which have been established for rating class A transformers and reactors used for grounding purposes. (See AIEE Proposed Standard No. 32, Neutral Grounding Devices and ASA Standards C-57.)

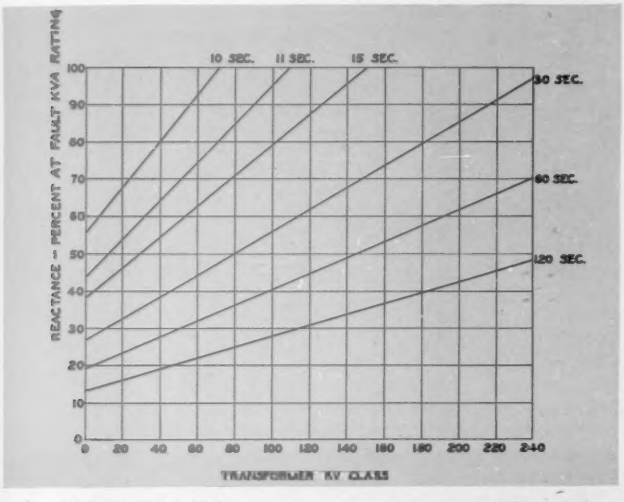
Service	Time Seconds	Calculated Copper Rise Above Amb. in °C	Initial Temp. Rise in °C	Amb. Temp. in °C
Feeder Fault Protection	11 to 120	125	Continuous Load Rise*	30
App. Fault Protection	10	160	Continuous Load Rise*	30
Power Transformation	2 to 5	220		30

* The initial temperature rise when no continuous load is specified is the oil rise due to core loss only of the transformer. When a continuous load is specified in addition to the grounding transformer rating, the initial temperature rise is equal to the hot spot copper rise for the specified continuous load.

When grounding devices are used to supply ground currents on feeders during fault conditions, the calculated rise above ambient has been standardized at 125 C and in most cases the time rating is one minute. A calculated temperature rise of 125 C



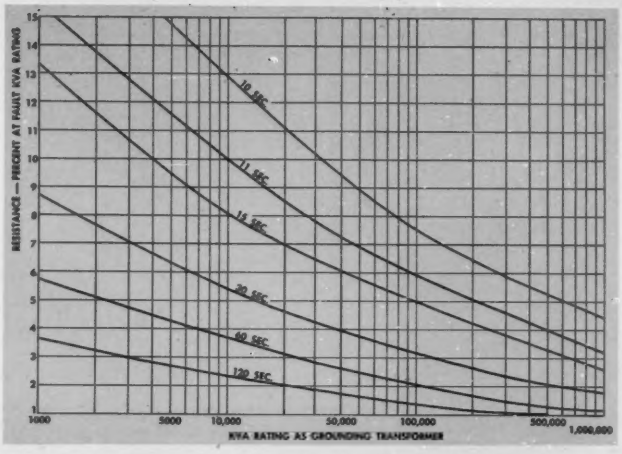
EQUIVALENT KVA CAPACITY of 3-phase delta-wye grounding transformers shown in typical curves, time ratings indicated in seconds. **(FIG. 4).**



NORMAL REACTANCE of typical 3-phase, delta-wye grounding transformers is indicated. Base for the reactance is fault kva rating. **(FIG. 5).**

is satisfactory because the service is intermittent and the total time this temperature exists during the useful life of the transformer is small. The length of time for the rating of the grounding transformer is determined by the short circuit duty, which is the interrupting time multiplied by the number of recurrent operations before the transformer is allowed to cool to normal, plus an allowance for any continuous load. It will be noted from Figure 4 that the longer the time rating the less the effect of a small continuous load on the size of the grounding transformer. Very small continuous loads have practically no effect on its size. The one minute time rating, as it is normally used, does make allowance for a small continuous load. Grounding transformers for feeder fault protection are usually so applied that their fault kva rating is the same as the maximum fault kva which flows through them. Since they are subject to more frequent operation than grounding devices for other applications, their time and temperature ratings are the most conservative of the three classes.

Grounding devices of the second class are used to limit the value of fault current which may flow through a given piece of apparatus as, for example, to limit the current in the neutral of a star-connected generator or transformer. The kva rating of grounding devices for



NORMAL RESISTANCE of typical 3-phase delta-wye grounding transformers is shown. Base is fault kva rating of transformer. **(FIG. 6).**

apparatus fault protection is usually based on the fault current, being limited only by the impedance of the apparatus plus the impedance of the grounding device. However, there is usually other impedance in series to the point of short circuit, so that most fault currents are less than the grounding device current rating.

The calculated temperature rise of 160 degrees has been set up for grounding transformers used for apparatus fault protection. This value is higher than the value used for feeder fault protection because apparatus short circuits resulting in full fault currents occur less frequently and last for shorter times; hence, the total time the maximum temperatures exist during the useful life of the transformer is less. The effect of series impedance in reducing the actual value of short circuit current below the rated value is also a factor.

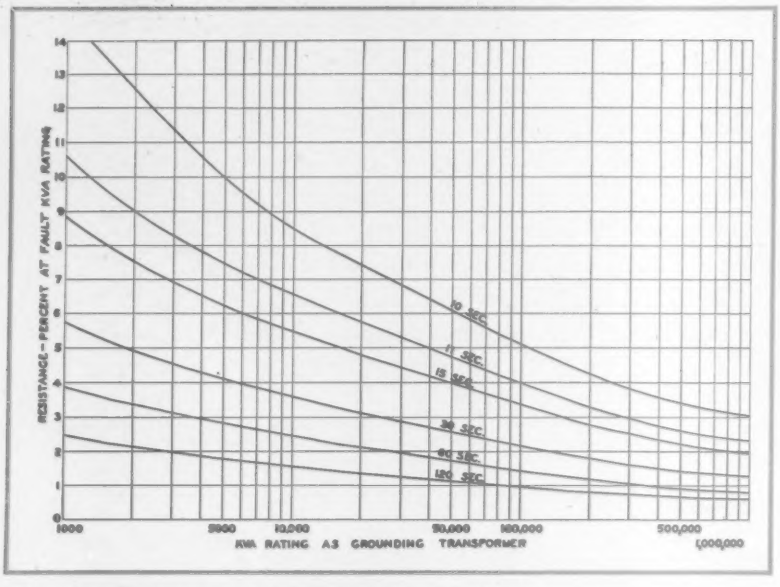
The time of 10 seconds which is used for most apparatus fault protective devices is shorter than is used for feeder faults because this equipment is normally provided with the same short circuit protection as the apparatus, which results in a shorter duration of each fault which occurs. Such devices are not subject to automatic reclosing service with full fault current. The time of 10 seconds is longer than the fault time rating of the apparatus it protects so that the device will not be the limiting factor in loading and will have some continuous load capacity.

Apparatus which is principally used for power transformation, but is also used for fault protection, may have a temperature rise of 220 C under fault conditions and the fault time is generally 2 to 5 seconds, depending on the design. This temperature rise is higher than for either of the other classes of grounding service because of the following factors:

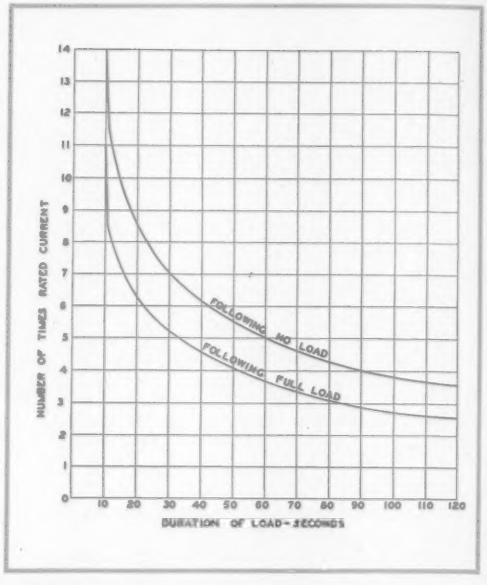
1. The effect of series impedance reduces the fault kva. Rated kva is based on fault current and is limited only by the impedance of the transformer. As actually applied, there is practically always considerable impedance in series, so that the fault current seldom reaches the full short circuit value of the transformer alone.

2. The assumed initial temperature rise of 65 C usually does not exist when the fault occurs. Consequently, the heating is less severe than that permitted.

3. The time of 2 to 5 seconds corresponds to the natural characteristics of power transformers and has been chosen to seldom result in increased size of transformer.



ZIGZAG-CONNECTED, 3-phase grounding transformer has typical normal resistance shown by these curves, based on design data for typical transformers. (FIG. 7).



OVERLOAD CAPACITY of typical continuous rated transformers as grounding transformers following no-load and full-load for various fault load durations. (FIG. 8).

The same factors that permit a higher temperature rise also permit a shorter time rating than for other classes of grounding service. In addition, the time should be shorter than the grounding device used with it so that the grounding device will not be the limiting factor in the application. Another reason why longer time is not required is that the continuous load is provided for by the normal rating of the power transformer and any continuous neutral current is included in the load current. Consequently, no increase in time to allow for this factor is necessary. A short time rating is satisfactory because a transformer used mainly for power transformation can be given the same protection for ground fault currents as for other fault currents without causing unnecessary service interruptions.

The time rating of a grounding transformer may be increased as an approximate method of allowing for unbalanced load currents to ground of considerable duration, or by specifying a shorter time rating combined with a continuous load rating. The latter method is more desirable since it is the more accurate method.

Grounding transformer characteristics

Using the temperatures of the table and the formula for calculating temperature rise, combined with design data for typical transformers, the curves of Figures 4 to 8 are derived for typical transformers. Figure 8 shows the number of times rated current which can be carried by typical power transformers following continuously no-load or following continuous full-load for various fault load durations.

The permissible fault current of a grounding transformer varies inversely as the square root of the time the load is carried, provided the mechanical strength limitations of the transformer are not exceeded. For example, the permissible load for four times the time is one-half the previous load.

Figure 5 shows the typical normal reactance of delta-wye grounding transformers for various time ratings and for various kv classes of transformers. The reactance voltage is expressed in percent of the line to neutral voltage when the kva carried corresponds to the fault kva for the time given. The typical normal reactance of a zigzag grounding transformer is approximately two-thirds of the reactance shown in Figure 5. Figure 6 shows the typical normal resistance of delta-wye grounding transformers for various time ratings and for various kva ratings of grounding transformers. The kva rating of a grounding transformer is defined as the symmetrical RMS fault current in the neutral multiplied by the normal line to neutral kv. Figure 7 shows similar values for zigzag connected grounding transformers.

In most cases, the normal reactance of a grounding transformer as shown by Figure 5 will be too low for grounding transformers having standard time ratings of 10 seconds or more unless neutral impedance is used to limit the fault current. If shorter time ratings could be used, it would not be necessary to increase the reactance. Consequently, most grounding transformers are designed for higher reactance than the normal reactance shown by Figures 5 and 6. When the reactance is greater than shown by Figure 5, the percent resistance as shown by Figure 6 will be increased approximately as the square root of the ratio between the reactances. For example, if the reactance of the grounding transformer were four times the reactance as given by Figure 5 the resistance would be the square root of 4 or twice the resistance given by Figure 6.

The effect of continuous load in addition to the grounding transformer rating for delta-wye transformers was shown in Figure 4. For zigzag transformers the kva parts are approximately 58 percent of the kva parts for delta-wye transformers. It will be noted that loads below 2 percent of the rating of the grounding transformer have little or no effect on the equivalent kva parts.

The term "kva parts" is used to represent an approximation of the physical size and weight of a transformer. Consequently, the kva parts size may be used for comparative purposes to determine the relative size of power and grounding transformers. Because of variations in design proportions between units, the

relation is approximate. For example, if the kva parts of a grounding transformer are 1000 kva, the grounding transformer will be of approximately the same size and weight as a 1000 kva power transformer of the same voltage class.

Figure 4 is constructed for transformers having normal reactance and resistance as shown in Figures 5 and 6. If the reactance and, consequently, the resistance is greater than shown in Figures 5 and 6, the continuous load to be used in determining the kva parts from Figure 4 should be increased in direct proportion to the percent resistance in order to provide for the increased heat to be dissipated.

The curves shown are for typical transformers. If more accurate values are desired for any particular transformers, they may be calculated from the fundamental formula and the design and test data of the transformers. However, these curves are suitable for estimating purposes, since the characteristics of modern commercial transformers seldom differ greatly.

Feeder fault applications

A typical grounding transformer application for feeder fault protection is illustrated in Figure 9. The total positive phase sequence impedance from a 110 kv system to the 13.8 kv bus is 4.43 + j17.0 percent on a 10,000 kva base. Scalar Zp is 17.6 percent at an angle of approximately 75.5 degrees. The grounding transformer duty may now be specified: Grounding transformer, three-phase, zigzag, 13,800 volts, to carry 62.5 amperes neutral current continuously. Impedance shall be such that with system positive and negative phase sequence impedances to the 13.8 kv bus of 4.43 + j17.0 each on a 10,000 kva base, the maximum voltage to neutral on an unfaulted conductor for a fault to ground at the terminals of the transformer will not exceed 125 percent of the normal line to neutral voltage. The total neutral current during this fault will be the rated fault current of the transformer carried for 30 seconds without injurious heating.

Assume for a first trial approximation that Zo = 2.5; Zp = 2.5 × 17.6 = 44 percent and that the angle of Zo is the same as Zp. Then

$$\text{Fault kva} = \frac{100 \times \text{base kva}}{Zp + Zn + Zo} = \frac{100}{17.6 + 17.6 + 44} \times 10{,}000 = 12{,}600 = \text{tentative rating of transformer.}$$

Normal percent reactance for a 30 second delta-wye transformer (Figure 5) = 31 percent on a 12,600 kva base.

Normal percent reactance for a zigzag transformer = ⅔ of 31 = 20.7 percent on a 12,600 kva base (16.5 percent on a 10,000 kva base).

Normal percent resistance (from Figure 7) = 3.4 percent on a 12,600 kva base (2.7 percent on a 10,000 kva base).

Percent resistance on a 10,000 kva base corresponding to 44 percent reactance = $\sqrt{\frac{44}{16.5}} \times 2.7 = 4.4$ percent, since the percent resistance varies as the square root of the reactance.

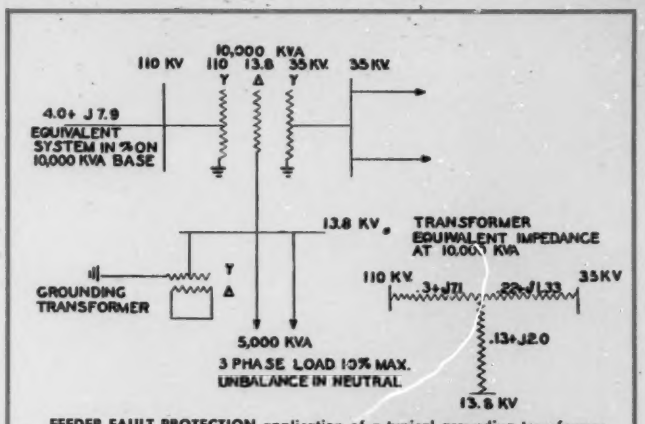
The impedance of 44 percent is composed of 4.4 percent resistance and 43.6 percent reactance.

Impedance = 4.4 + j 43.6 = 44∠84.7 degrees

Angle of departure = 84.7 − 75.5 = 9.2 degrees

From Figure 3, the voltage on fault = 124 percent — compared to 125 percent specified.

The recheck of the fault calculations using the actual grounding transformer impedance therefore shows



FEEDER FAULT PROTECTION application of a typical grounding transformer is illustrated in this diagram of a 110 kv distribution system. (FIG. 9).

that the 12,600 kva tentative rating is correct in the final stage.

$$\text{Continuous load} = 62.5 \times \frac{13.8}{1.73} = 500 \text{ kva}$$

$$\text{Load} = \frac{500 \times 100}{12{,}600} = 4 \text{ percent of grounding transformer kva.}$$

Because of the increased percent resistance due to the increased percent reactance above normal, the heating with continuous load will be increased. To allow for this, the continuous load value for Figure 4 is increased in the ratio of the percent resistances:

The heating corresponds to a load of $\frac{4.4}{2.7} \times 4 = 6.5$ percent of the grounding transformer kva.

From Figure 4, corresponding to a load of 6.5 percent on the 30 sec. curve, the kva parts = .135 × 12,600 × .58 = 990 kva.

Power transformers for grounding

Conventional power transformers are frequently used as grounding transformers, although they do not have the ability to carry the maximum fault current for as long a period of time. However, the maximum current exists only for faults close to the grounding transformer and as fault current decreases rapidly as the distance from the station increases, conventional power transformers usually will be entirely satisfactory if installed to furnish a neutral connection classed as "effectively grounded" according to the standards herein described.

The grounding transformer actually installed in the example of Figure 9 consists of a conventional wye-delta transformer bank of three 250 kva, 8000-2400 volt transformers having impedances of 1.09 percent R, and 3.20 percent X equal to (14.53 + j42.67) percent on a 10,000 kva base. Scalar impedance is 45 percent at an angle of approximately 71.25 degrees. The angle of the positive phase sequence is 75.5 degrees with a plus departure of 4.25 degrees. Zo/Zp is 45/17.6 = 2.55, which it will be seen by reference to the curves of Figures 2 and 3 will just meet the voltage rise requirement. Maximum fault current in each transformer for a single line to ground fault at the transformer terminals is:

$$\frac{100 \times \text{base amperes}}{Zp + Zn + Zo} = \frac{100}{23.39 + j76.67} \times 417 = 516 \text{ am-}$$

peres scalar. Rated current of each transformer is 31.25 amperes. Maximum fault current, therefore, is 16.5 times the rated load current. From Figure 4, 11.0 times normal current can be carried for 10 seconds as a grounding transformer following full-load or 14 times normal current following no-load.

Following full-load, 16.5 times full load (the fault current) can be carried for $\left(\frac{11}{16.5}\right)^2 \times 10 = 4.5$ seconds.

Following no load, 16.5 full load (the fault current) can be carried for $\left(\frac{14}{16.5}\right)^2 \times 10 = 7.2$ seconds.

A comparison of these two grounding transformers—(1) 12,600 kva 30 second grounding transformer zigzag connected, (2) a 750 kva, continuously rated power transformer—is shown in the tabulation.

TRANSFORMER	NO. 1	NO. 2
Connection	Zigzag	Star Delta
Continuous kva	500 kva	750 kva
Equivalent kva parts (physical size)	990 kva	750 kva
Grounding transformer rating (Following 500 kva continuously)	12,600 kva	12,400 kva
Time in seconds	30 seconds	6 seconds

The relative sizes of the two grounding transformers are represented by their respective kva parts—990 kva for the zigzag and 750 kva for the star-delta power transformer. Because of the 30 seconds time as compared to the 6 second time rating of the star-delta transformer the zigzag is much larger physically. However, if the time rating of the zigzag transformer should be reduced to 10 seconds, the kva parts would be approximately 580 kva and the zigzag transformer would be smaller, less expensive and still have a better time rating.

Conclusions

Where no voltage transformation is involved, a zigzag-connected grounding transformer is considerably smaller than a star-delta unit of the same time rating, the kva parts being approximately 58 percent of those of the star-delta unit.

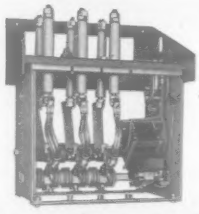
Star-delta power transformers of 2 to 5 seconds short-circuit time rating will provide satisfactory service as grounding transformers in many cases. However, they will be larger than zigzag grounding transformers having time ratings relatively much longer than the star-delta transformers. The only advantage of the star-delta transformer is that it can be used as a power transformer if the occasion should arise.

The curves of transformer characteristics show typical values for transformers to be used as grounding transformers. They will be found to be sufficiently close for estimating purposes.

The curves of fault voltages (particularly in Figure 3) show the necessity of taking into account the difference in phase angle between positive phase sequence impedance and zero phase sequence impedance. They also show the great importance of knowing the resistance of neutral connections. A system can be "solidly grounded" but, unless the ground connection has resistance, which is a negligible part of the system fault impedance, it will not be "effectively grounded."

New Equipment

New "MO" Contactor Is Oil-Immersed For Heavy-Duty Motor Starting



Designed for heavy-duty motor starting service in industrial plants, a new type "MO" oil-immersed contactor is now available. The new contactor (illustrated with barriers and tank removed) is built in 100 and 200 amp sizes, and can be used with motors rated up to 900 hp at 2300 volts.

The new steel frame construction of this clapper type contactor insures greater rigidity and perfect alignment of parts. An E-type magnet and an a-c coil with armature directly connected to the contactor shaft through a universal joint gives longer service and quieter operation.

Extra heavy copper contacts give long life because the contactor mechanism causes the moving contact to roll and wipe on each operation, keeping it clean. Arcing is done on the tips, not on current-carrying areas, for lower maintenance. Contact tips are easily replaced. Removing just one screw on either the stationary or moving contact makes the contact tip immediately available for inspection.

Ample insulation is provided by wide pole spacing, plus barriers, and Bakelain high dielectric bushings. Special anti-creepage shaft insulation and oil immersion of the entire contactor, including coil, are provisions for greater safety.

New Slurry Pump Built For Materials Handling And Sludge Disposal

A new type "CW" slurry pump, designed for solid, abrasive, and corrosive materials handling and sludge disposal in metal and non-metallic mining industries, has been introduced recently. The first of a number of expected applications for the new pump has been for coal washing service.

This new "CW" pump is constructed of the tough abrasive-resistant alloy (silimite) developed for exclusive use on Allis-Chalmers products. Laboratory and field tests show that this alloy plus the special pump design increases type "CW" slurry pump life two to four times over pumps constructed of ordinary materials.

Simplified design of the entire unit results in fewer parts than any comparable pump, requiring minimum maintenance. The entire rotating element can be removed without disturbing the suction or discharge piping. Efficiencies of the "CW" slurry pump are comparable to those of ordinary high efficiency clear water pumps.

Seven sizes have been developed to handle through 7000 gpm. Stocks of complete units as well as expendable replacement parts are to be maintained in strategic areas. Complete details are available in Bulletin B6381.

Regulator Economy Chart TELLS THE STORY

Tabulated below are savings you get by using Allis-Chalmers 5/8% Step Regulators rather than Induction Regulators on 2400 volt feeder lines.

2400 VOLT REGULATOR RATING	POWER SAVINGS (Reactive Kva Eliminated From Lines)	DOLLAR SAVINGS (Approximate Cost of Compensating Capacitors)
36 kva	6.1 kva	$37
48 kva	8.1 kva	$49
60 kva	10.2 kva	$61
72 kva	12.2 kva	$73
96 kva	16.3 kva	$98
120 kva	20.4 kva	$122

BECAUSE of the magnetic gap between rotor and stator, induction regulators need about *three times* as much excitation as the Allis-Chalmers 5/8% Step Regulator.

Conversion of this additional exciting current into revenue-producing loads can be accomplished in two ways: 1) By installing capacitors — which may cost about $6 per kva, or 2) By use of Allis-Chalmers DFR Regulators instead of induction regulators. The above chart demonstrates the savings you get by employing the *second method*.

Further advantages of Allis-Chalmers DFR 5/8% Step Regulators for low voltage, single-phase feeders: No hunting or overshooting; quieter operation; voltage integrator and Feather-Touch control, providing better average regulation than any other type of feeder voltage regulator.

To get the full story on A-C feeder voltage regulators, call on our nearby district office, or write for Bulletin B-6065 and B-6056A. ALLIS-CHALMERS, MILWAUKEE 1, WISCONSIN. A 1825

ALLIS-CHALMERS *5/8% STEP REGULATORS*

OSCAR A. HAAS.
ASSISTANT MANAGER
ENGINE & CONDENSER

2-in-1 Substation Saves Mill Space

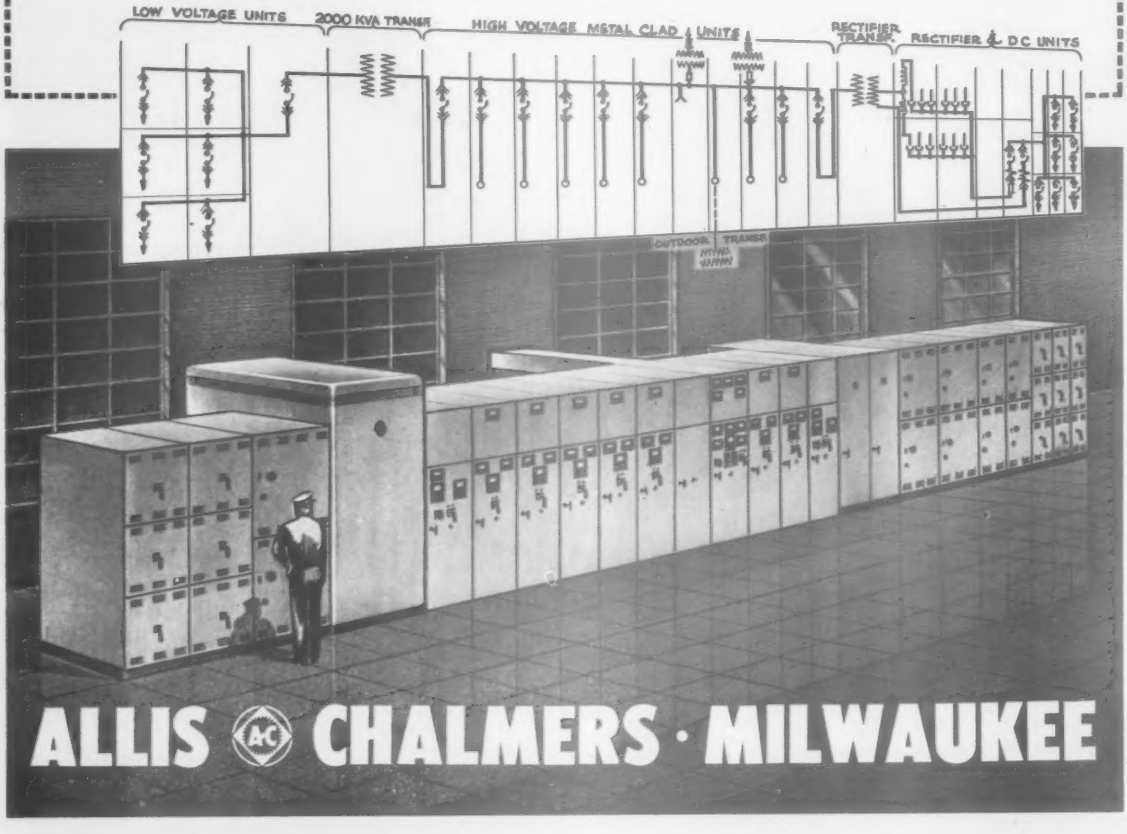
A-C AND D-C LOADS SERVED BY COMPACT UNIT

A SUBSTATION tailor-made for steel mills having highly-concentrated and diversified loads, as shown in the artist's sketch below, is now offered by Allis-Chalmers.

Because it comprises a 2400 volt multi-circuit substation, an a-c load center substation, and a d-c load center substation in a single unit, it is called a "packaged" substation. This compact arrangement of switchgear and transformers saves valuable floor space ... installation time ... and operator's time.

Through use of the new 2000 kva streamlined, dry-type transformer, and switchgear which contains "Ruptair" magnetic air circuit breakers, Allis-Chalmers has achieved a *totally oilless* metal-clad installation.

At the d-c end of the substation is a 500 kw rectifier — the *permanently-sealed Excitron* — which requires minimum maintenance.

For easy accessibility, both "Ruptair" circuit breakers and potential transformers are drawout in construction. Get further details on this modern substation from our nearby district office, or write direct to ALLIS-CHALMERS, MILWAUKEE 1, WISCONSIN.

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